ACP
AUTORIDAD DEL CANAL DE PANAMA
Oficina de Proyectos de Capacidad del Canal

THE PANAMA CANAL

Work Order No. 1
EVALUATION OF LOCK CHANNEL ALIGNMENTS

CONTRACT NO. CC-5-536

Review of Excavation Methodologies
Part 4 of 4

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HARZA Engineering Company, Inc.
In association with
TAMS Consultants, Inc.

THE PANAMA CANAL
EVALUATION OF LOCK CHANNEL ALIGNMENTS

PART 4 – REVIEW OF EXCAVATION METHODOLOGIES

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1.0 INTRODUCTION

The proposed new lock channel alignments for the Panama Canal will require between 40 and 140 million cubic meters of excavation. The cost of removing and disposing of this material may comprise half or more of the cost and construction period for the project. Planning and engineering the excavation and disposal will reduce cost and accelerate the schedule. This report section reviews some past and current projects involving large-scale excavation and disposal in order to identify which excavation techniques may achieve the greatest efficiency for the project. It also surveys future trends in massive earth moving. Finally, it provides recommendations on what equipment and techniques will be most useful for the new lock channel alignment excavations (see Exhibit 1).

Channel excavation will take place in both wet and dry conditions. Wet excavation generally refers to any excavation that takes place under water. This includes dredging and land-based equipment working below the water surface. Dry excavation includes any excavation in dry conditions including dewatered areas. Excavation will be required in overburden (generally known as "common") and rock materials. Common excavation includes removal of loose and compacted soils that may contain gravel or some fragmented rock. Rock excavation includes removal of weathered and unweathered (sound) rock. Both weathered and sound rock may be excavated with or without pre-treatments such as ripping or blasting according to its compressive strength and other qualities. In general, any rock with a compressive strength over 30 to 40 Mpa (4350 to 5800 psi) must be blasted prior to excavation.

Many of the techniques reviewed may be applicable to excavation for new lock channel alignments. Blasting will be necessary in many areas. Nearly all rock is covered by soil overburden in both dry and wet conditions. Thus each excavation area will likely require at least two sets of equipment – one well suited for common excavation and one well suited for rock excavation. In general, minimizing wet excavation will lead to the lowest overall excavation costs.

Supplementary material is contained in appendices to this report. Specifications and capacity details for selected wet excavation equipment appear in Appendix A. Appendix B provides additional information on selected dry excavation equipment. The latest Global Positioning Equipment is highlighted in Appendix C. Finally, the references are given in Appendix D.

2.0 REVIEW OF EXISTING APPLICATIONS AND METHODS

The past two decades have witnessed many important earth and rock moving projects throughout the world. These include both underwater excavation and reclamation (wet) and surface excavation (dry). Some projects, such as the construction of Hong Kong's Chep Lap Kok Airport, are comparable to the original Panama Canal excavation in magnitude. Excavation techniques employed in these projects were reviewed as possible alternatives for excavation under the varied conditions presented by the proposed channel alignments.

Specialized wet and dry excavation equipment exists for all material types. In general, the heavy-duty cutter suction dredge and the high capacity backhoe dredge are the best suited for underwater blasted and unblasted rock excavation. Both can perform underwater common excavation efficiently as well. Suction and clamshell dredges are suited for common excavation but not for rock. Similarly, land-based backhoes and wheel loaders are the best dry equipment for blasted rock excavation. Scrapers and belt loaders are efficient for common excavation in dry conditions.

2.1 Wet Excavation Techniques

Wet excavation has historically meant dredging. Modern dredging techniques date back several hundred years. Many modern techniques and equipment were developed in the Low Countries of Holland and Belgium as they fought the encroachment of the sea and reclaimed land below sea level.

Dredges generally fall into three categories: hydraulic, mechanical and trailing suction hopper (see Appendix A, Exhibits A-2, A-3 and A-4). Hydraulic dredges excavate and move earth and rock by creating a slurry that is accelerated by centrifugal pumps. The slurry passes through large diameter pipes to a disposal area where the water drains off and the spoil is retained. Mechanical dredges usually load hopper barges (scows) that transport spoil to a designated disposal area where it is either bottom-dumped or hydraulically unloaded. Trailing Suction Hopper Dredges are ocean-going ships which use trailing arms to suck soft materials off of the bottom. The material is then placed in a hopper in the ship and transported to a disposal area.

Land based equipment (Exhibit A-6) may be economically used to perform underwater excavation as well. Backhoes and draglines are capable of digging loose and stiff soils below the water surface. They generally work in conjunction with land-based trucks, similar to dry excavation.

The following case studies present a variety of excavation techniques employed in massive underwater excavations and reclamations throughout the world. Some of these techniques may be applicable for the lock channel excavation.

2.1.1 Gaillard Cut Widening in the Panama Canal

In July 1991, the Panama Canal Authority (ACP) approved a long-range plan to improve the Gaillard Cut, the narrowest section of the existing canal, in order to allow two-way traffic of Panamax vessels in the entire canal. Dry excavation totaling 29.2 million m^3 began in January 1992. In January 1994, the ACP's Dredging Division was placed in charge of the wet excavation phase. The 11.5 m^3 dipper dredge *Christensen* has worked continuously on the project since 1994. The drill boat *Thor* performed drilling to blast rock for excavation. Since 1996, the cutter suction dredge *Mindi* and a land-based hydraulic excavator have aided the *Christensen* to increase production. The project is scheduled for completion in 2002.

In total, 11.4 million cubic meters of wet excavation are required for the Gaillard Cut Widening. As of October 1999, the underwater excavation was 60 percent complete. Based on current progress, the program has averaged approximately 115,000 m^3 of excavation per calendar month (including overhaul periods).

2.1.2 Chep Lap Kok Airport, Hong Kong

This project involved transportation of fill material to create a 1,248-hectare airport platform on an artificial island. A total of 347 million m^3 were moved over a period of 41 months. In the peak period, over half of the world's dredging fleet was employed on the project, moving over 400,000 m^3 of fill per day. The excavation and fill contract was valued at US$1.15 billion. Large (greater than 10,000 m^3 hopper capacity) trailing suction dredges transported most of the fill from offshore borrow areas to the project site. Cutter Suction Dredges (CSD) also provided fill from nearby borrow sites. These techniques can be applied in reverse as well with large trailer and CSD dredges removing excavated materials to nearshore or upland disposals.

2.1.3 Expansion of the Port of Lazaro Cardenas, Mexico

Nearly five million m^3 were hydraulically dredged and mechanically excavated to double the entrance channel width and provide new berthing areas for coal carrying ships. Much of the excavated material was cobble-sized gravel with some fragmented rock. The owner was able to reduce costs by selling good fill material to contractors. Land-based backhoes were able to excavate part of the new dock area as much as three meters below the water surface. One medium-sized electric-powered cutter suction dredge dug and placed an average of 600,000 m^3 of spoil per month. A small hopper dredge added 200,000 m^3 per month. The material was re-handled by wheel loaders and 18 m^3 hopper trucks to designated areas.

2.1.4 Kill van Kull Channel, New York, USA

Blasted rock was dredged from the waterway leading from New York Harbor to the Port of Newark. The spoil was loaded into hopper barges and towed over 40 km to offshore disposals to create artificial reefs. Dipper and clamshell dredges were both utilized. Some of the material was deemed unsuitable for offshore disposal and was placed in nearshore cells and capped with clean sand. The world's largest backhoe dredge with a bucket capacity of 19 m^3 (see Appendix A, Exhibit A-2) has been employed on this project. The current project involves removal of over nine million m^3 of rock and sand.

2.1.5 Öresund Fixed Link, Sweden & Denmark.

Dredging of over seven million m^3 of rock and sand began in October 1995. Much of the spoil was reused to build an artificial island. The works were completed with both mechanical (dipper and backhoe) and hydraulic dredges. Real Time Kinematic (RTK) GPS receivers were utilized to ensure exact positioning and a level bottom within a tight tolerance.

2.2 Dry Excavation Techniques

Dry excavation generally refers to digging and hauling earth and rock on land or in dewatered areas. Wheel loaders, hydraulic shovels, scrapers and draglines are the most commonly used excavation equipment. Large off-highway trucks are usually employed to haul spoil to designated disposal areas. Haul roads must be specially constructed to accommodate the weight of these trucks. In the case of rock excavation, a tractor equipped with a ripper may be used to loosen weathered rock of compressive strength up to 30 to 40 Mpa (4350 to 5800 psi). Harder rock must be drilled and blasted prior to excavation. In either case, a bulldozer is employed in the disposal area to spread and level the spoil.

2.2.1 Eastside Reservoir Project, California, USA

The Eastside Reservoir Project involved the excavation and movement of 115 million m^3 of sand, clay and rock. Most of the spoil was used to construct earthen dams at either end of a valley. Blasting loosened an average of 95,000 m^3 of rock per day for excavation. The largest blast utilized over 90,000 kg of explosives. The contractors employed hydraulic excavators with bucket capacities up to 17 m^3 and front-end loaders buckets up to 20 m^3 (see Appendix B, Exhibits B-3 and B-4) to remove blasted rock. The largest available off-road trucks capable of hauling up to 200 tons (see Appendix B, Exhibit B-2) were employed in order to maximize excavation and hauling efficiency. The excavation will be flooded later to form a reservoir that will serve as a six-month emergency water supply for the city of Los Angeles, California.

Vertical side-cutting belt loaders excavated and loaded the majority of soft overburden material (see Appendix B, Exhibit B-7). They can cut 3 to 6 m high face of alluvial material with each pass. A belt transferred the material to 92 m^3 bottom-dump trucks that hauled the material 3 to 6 km at an average speed of 55 km/hr on eight- percent grades. The weight of the trucks in the disposal area helped with compaction.

Each day, some 50,000 tons of rock was crushed and processed on the work site for use in dam construction. This temporary operation was larger than any other commercial rock processing plant in the state of California, USA. The scale of the project made the initial equipment investment feasible. A similar operation may be feasible to create concrete aggregate for the new locks construction in Panama. One crusher site might be adjacent to the Cerro Paraiso excavation.

Using the largest commercially available equipment, excavation works on the Eastside project were completed in 45 months. In order to move 2.5 million m^3 of earth and rock during each working month, the contractors employed two ten-hour shifts per day, five days per week and two eight-hour Saturday shifts. Work was not performed on Sundays partly due to union wage requirements in California. In Panama, seven day per week work may be possible.

Several of the Eastside project's applications may be employed in the excavation of the proposed lock channel alignments in Panama. Belt loaders working with bottom-dump trucks could effectively load soft overburden in dry conditions. Working multi-shift days and using the latest and largest equipment could considerably accelerate the excavation schedule and reduce unit costs. Finally, the use of an on-site crushing plant may reduce the cost of producing aggregate and fill materials for dams.

2.2.2 Interstate 26 Construction, North Carolina and Tennessee, USA

The first phase of the project required excavation of 10 million m^3 of rock and 10 million m^3 of earth in cuts up to 183 m deep. Much of the excavated material was reused in high embankments. The Engineer performed extensive soil tests and used probabilistic models to determine the maximum safe slopes and thus minimize the cut quantities. Hauling material was difficult due to the mountainous conditions and heavy winter rainfall. Disposal of material was hampered by grades up to 12 percent on the haul road, which reduced truck speeds significantly. The contractor has employed up to seven off- road haul trucks by Caterpillar (models 785, 789 and 793 – See Appendix B). Soil excavation was performed largely with Cat 657 Scrapers while a single Cat 5230 Excavator equipped with a 20 m^3 bucket removed blasted rock. The contractor initially intended to rip some rock and blast the rest but found blasting all of the rock more economical. Overall production amounted to approximately 500,000 CY per month working two ten-hour shifts per day with approximately 24 effective days per month.

A second phase of the project included excavation of eight million m^3 of material. Because of the extreme grades on the haul roads, the contractor utilized smaller equipment than the first phase. Three Demag excavators equipped with 12 m^3 buckets fed a fleet of 17 Cat 773 (150 ton) off-road dump trucks. The smaller trucks were able to negotiate grades up to 15 percent and required haul roads of only 9 to 12 m in width.

2.2.3 Guri Dam, Venezuela

The Guri Project involved movement of over 26 million m^3 of earth and rock. Belt loaders manufactured by the Holland Loader Company excavated much of the soil. The loaders were sandwiched between Caterpillar D-9 tractors (see Appendix B, Exhibit B-7). They filled hopper wagons that were towed to disposal areas and bottom dumped.

2.3 ACP Excavation Experience in Panama

The Panama Canal Authority possesses excavation equipment and expertise to complete the proposed project. Throughout the 86 years of canal operation the ACP has gained a wealth of experience in blasting, dry excavation and dredging. Annual maintenance dredging and capital improvements such as the Gaillard Cut widening have kept the medium-sized cutter suction dredge (CSD) *Mindi* and the 11.5 m^3 dipper dredge *Christensen* occupied. In emergency situations and for maintenance of the entrances, the ACP has also supervised work it contracted out to foreign dredging companies.

2.3.1 Wet Excavation

The ACP's Engineering division is responsible for maintenance dredging of the 82 km channel from sea buoy to sea buoy. Each year ACP equipment removes over 1 million m^3 of sediment to maintain sufficient draft for vessels transiting the canal. The PCA employs three major floating excavation tools as well as a number of supporting tugs, scows and work barges. Details on the dipper dredge *Christensen* and the CSD *Mindi* are provided in Appendix A, Exhibits A-2 and A-3. The PCA also operates a backhoe excavator manufactured by Liebherr. The Litronic 994 (see Exhibit A-6) has augmented the ACP's wet excavation capabilities. It removes earth and blasted rock from side slopes of the channel at roughly half the cost of the *Mindi* or *Christensen*. Similarly, the land based drilling rig used by the ACP performs side slope blasting at half of the drillboat *Thor's* cost.

2.3.2 Dry Excavation

The ACP has contracted out nearly all of the dry excavation associated with the current Gaillard Cut widening program. Under the ACP's management, 90% of dry excavation has been completed under 16 separate contracts. Contract costs for dry excavation have averaged US$3.30 per m^3. Land-based drilling and blasting costs have averaged an addition US$3.30 in dry conditions. The ACP maintains a good safety record for both its wet and dry blasting programs.

2.4 Disposal Methodologies

All of the proposed alignments include a common problem: disposal of the spoil. The conventional method of minimizing spoil by balancing cut and fill is not applicable since the project amounts to simple excavation. The hilly terrain and the presence of ubiquitous tropical vegetation present further difficulties. Thus, non-conventional disposal techniques were analyzed alongside more commonly used methods. Further, the character of the spoil will play a large role in determining its final destination.

2.4.1 Mechanical Wet Excavation Disposals.

Exhibit 2 shows some potential spoil disposal areas for the Pacific Entrance wet excavation. Some areas may offer environmental benefits such as wetland creation to the region if properly engineered. Others may allow beneficial reuse of the spoil either on the project or outside of it. Several of the Pacific Entrance alternatives require construction of dams. Much of the spoil should be suitable for these uses. For example, the proposed barrier dam separating the bypass channel from the existing channel in Alignment P2 could be constructed with suitable rock fill.

The wetland on the bank opposite the Port of Balboa is another potential disposal area. With approximately 1,000,000 m^2 surface area, the site could accommodate up to 10 million m^3 of hydraulic fill. It would require drainage and the environment would be changed. However, the environmental changes could be mitigated by creating a similar wetland with hydraulic spoil in the bay just inside of the Bridge of the Americas. The creation of wetland habitats requires environmental evaluation.

Fortification of the Amador Causeway represents another opportunity to use barge-transported spoil. Bottom-dump barges could fill deeper draft areas while some areas might require mechanical unloading. The same techniques could be used to construct additional breakwaters. Quality material may also be recycled into aggregate. Backhoe dredges may be outfitted with an aggregate processing plant on their decks as with Dredging International's *Samson*. Other prospective customers for fill might be the Port of Balboa, Municipality of Panama City and local developers.

Nearshore reefs could be constructed with spoil material as well. Reefs could serve to protect the shoreline by reducing wave energy. Artificial shallow water areas might also create new fish habitats that could help both the environment and the economy. Offshore disposal areas present unlimited capacity. Trailing suction hopper dredges or tug-towed dump barges can perform open-water disposal. Mechanical or hydraulic dredges may be used to fill the barges. The cost is largely a function of the haul distance. High capacity hoppers would be required for long hauls to disposal areas.

Finally, some alternatives propose flooding of new areas adjacent to the new lock channel. Much of the newly flooded area could be reclaimed with the spoil excavated from the new channel. In the best case, a high capacity grab dredge with a long boom could sidecast material into newly flooded areas eliminating the need for barge transportation.

2.4.2 Dry Excavation Disposal and Hydraulic Dredging Disposal

Both dry excavation and hydraulic dredging generally utilize upland disposals. Upland disposal present similar difficulties to mechanical wet excavation disposal. Costs increase with haul/pump distance. Weather plays an important role as well. Heavy rains will make excavation, handling and disposal difficult in upland areas. Upland disposal near to the cut area is the most obvious dumping site. This is generally the most efficient, least costly option when available. Dry excavators load trucks in the cut, which transport the spoil to the site by a haul road. Tractors are used to level the site to ensure proper slopes and efficient use of the available land. Similarly, low-lying areas may be filled in by spoil from dump trucks or pumped hydraulic fill.

It is likely that suitable construction materials will be excavated in the cut area. Developers may want to purchase fill in excess of that needed for the project. Similarly, quality aggregate from basaltic rock found in the alignment areas could be processed and separated from the spoil for use on site or for sale. Use of spoil for construction or sale would have the double advantage of reducing the disposal volume and adding revenue to the project. Finally, fill could be loaded on conveyors from the cut and transported to hopper barges. Disposal options would then be the same as listed under wet disposal options.

Potential disposals adjacent to the excavation areas for wet and dry excavation are mapped on Exhibit A-3 (Atlantic entrance) and A-5 (Pacific Entrance) in Part 3, Appendix A. For both entrances, some disposals are available for each alignment. Which disposals are available depends on the geography of the alignment. Some of the disposals assume mounding as high as 20 m above original ground to accommodate the massive excavation for the new alignments. Individual disposal capacities are provided in a table at the bottom of each exhibit. These disposal capacities were not verified. However, the locations provided offer a starting point for investigation once final alignments are chosen.

For the Atlantic Entrance, five disposal areas are proposed: two sites (E1 and E2) are located north and east of the 1939 excavation on the eastern shore of Limon Bay, and three sites (W1, W2 and W3) west of the existing Canal alignment. Areas E1 and E2 can be used for disposal of wet and dry excavation from either Alignment A1 or A2. Depending on the selected alignment, the volume of wet excavation will vary greatly: in the case of Alignment A1, the volume of wet excavation could be entirely disposed of in area E2, however for Alignment A2, the capacity of this disposal site would be insufficient. Alternative sites for disposal of wet material could be either a part of area E1 or one of the sites identified on the west side of the Canal such as W2 or W3. Dry excavation for both Alignments A1 and A2 would be placed in area E1. Disposal areas for Alignment A3 would be located on the west side of the Canal (areas W1, W2 and W3).

For the Pacific Entrance, seven disposal locations are proposed for the east side of the canal and six disposals are proposed on the west side. Disposals E1 and E2 offer limited capacity for disposal of wet and dry excavation north of the Pedro Miguel locks. Disposals E4, E5 and E6 could accommodate hydraulic fill for the alignments using separate locks at Pedro Miguel and Miraflores as well as dry excavation disposal for the east side alignments. Disposals E6 and E7 offer dry excavation disposal for the east side alignments. Disposal W1 and W2 are the highest capacity potential disposals. W1 is a potential spoil site for much of the excavation of the Cerro Paraiso and adjacent areas. W2 offers both hydraulic fill capacity and a dry excavation spoil site. Disposal W3 offers additional capacity but its use would require rerouting of the Rio Cocoli. Disposals W4 and W5 are sited in the existing 1939 excavation. If these sites are not used for an alignment, their reclamation may be desirable to create a foundation for new water saving basins, operations areas and maintenance facilities. Finally, Disposal W6 is an existing spoil site and could be used for either hydraulic fill or dry excavation disposal.

All of the disposal areas require further investigation to verify topography and determine actual fill capacities. Use of several of the sites would also require some infrastructure relocation. That cost must be balanced against the cost of additional haul to more distant sites when determining whether a disposal site will be used or not.

3.0 SURVEY OF FUTURE TRENDS

The future of massive excavation rests with ever-increasing capacity in the equipment. Recent construction of both dry and wet excavation equipment has been focused on higher-capacity machines. Larger machines have reduced unit costs on large projects. When transportation distances are significant, greater-capacity vehicles are generally more cost-effective. Jumbo excavators are able to break and dig stiffer materials more effectively than smaller models.

Both wet and dry excavation techniques have benefited from advancements in surveying technology. Global Positioning System technology now allows precision underwater and dry excavation. Computer displays provide operators with positions accurate to one centimeter horizontal and two centimeters vertical. (See Appendix C for some of the latest GPS equipment.) Continued technological advances in surveying will further increase excavation precision and thus reduce costs.

3.1 Wet Excavation Techniques

Massive underwater excavation may take place by either land-based hydraulic shovels or mechanical or hydraulic dredges. Land-based excavators and walking draglines are effective in loose to stiff material and generally provide a low unit cost when filling dump trucks for nearby disposal. The former have limited reach while the latter are less mobile.

Dredges that could be used on the proposed alignments fall into three categories: hydraulic suction, mechanical and trailer. A large cutter suction dredge represents the best tool for moving large quantities of soft material for a short distance when good drainage is available at the disposal area. Recent construction in the industry has tended toward large dredges. They are capable of cutting weathered and sound rock up to 30 to 40 Mpa compressive strength without pre-blasting. Some are capable of pumping material several kilometers by large diameter pipe. The largest cutter suction dredges can pump over 80,000 m^3 per day. The hydraulic dredging industry is moving toward larger capacity machines suited for massive excavation such as that proposed. (See Appendix A for specifications on the latest dredging equipment).

Mechanical dredges are broken down into clamshell, dipper and backhoe. All three dispose of material into a dump scow, which must be towed to a disposal site for either bottom dump or pumpout. The first type is well-suited for soft material while the other two are capable of digging blasted and in some cases unblasted rock. As with hydraulic dredges, the industry trend is toward larger-capacity machines capable of excavation in harder materials. If an offshore disposal is nearby and large hopper barges may be used, mechanical dredges may offer a low unit cost.

The Trailing Suction Hopper Dredge generally performs offshore maintenance dredging and offshore mining. Future trends of hopper dredges mirror hydraulics and mechanicals: increased capacity. The latest series, including the *M/V Amsterdam* and *M/V Fairway*, have hopper capacities over 18,000 m^3.

Water Injection Dredges and specially designed cutters represent other recent innovations in the industry. The former is a low cost method of performing maintenance dredging in soft materials where natural currents exist. The latter are used when environmental restrictions limit turbidity. The industry also continues to seek beneficial uses of dredge spoil. Dredges can be suitable for environmental cleanups as well. Their role might be removing waste to a secure disposal or creating or sealing the disposal area.

The most important recent innovations in wet excavation that may apply to the proposed excavation are the new high-powered backhoe and cutter suction dredges (CSD). The recently constructed backhoe dredge *New York* (see Appendix A, Exhibit A-2) and the CSD *Leonardo da Vinci* (see Appendix A, Exhibit A-3) are ideally suited for excavation in the proposed lock channel alignments. These machines effectively and efficiently excavate weathered rock without blasting. They are also efficient when removing blasted rock and all types of overburden. The two offer capacity and production up to two times greater than their ACP counterparts, the *Christensen* and the *Mindi*.

3.2 Dry Excavation Techniques

As with wet techniques, dry excavation continues to seek larger capacity for massive excavation. An example of new equipment becoming available includes the Caterpillar 797 Large Mining Truck (see Appendix B, Exhibit B-2). The 797 will be commercially available worldwide in 2001 and has a payload capacity of 360 tons. Similarly, new portable hydraulic excavators such as the CAT 5230 ME (see Appendix B, Exhibit B-4) have bucket capacities up to 27 m^3.

Long-distance conveyors are another alternative for disposal. Conveyors offer the advantage of uninterrupted movement of material. Heavy-duty conveyors can transport three-foot diameter boulders as well as soil, gravel and cobbles. Similarly, belt loaders provide an alternative to traditional scrapers. They are used in combination with a hopper or dump truck. They have been effectively applied to overburden removal in massive excavations such as the Eastside Reservoir and the Guri Dam. In some situations they may provide both increased efficiency and lower fuel consumption than scrapers.

Another potential cost saving method could be pre-designed disposal areas. The owner may reduce the contract cost by providing contractors with prepared disposal areas. Vegetation may be used to stabilize side slopes and thus increase capacity in disposal areas. This technique was successfully used in the excavation for Interstate 26 in North Carolina, USA (see Section 2.2).

4.0 EVALUATION OF METHODOLOGIES

4.1 Wet Excavation Techniques

In general, land-based equipment provides lower unit costs than floating plant. However, floating plant will probably be required for some of the excavation of any of the proposed alignments. If well-drained disposal areas are available nearby, dredging costs may be comparable to land-based equipment for excavation of soft material. Dredging also may be competitive when dewatering an area is complicated or costly. Different styles of dredges are better suited to different materials that may be encountered in the alignments (see Exhibit 1). Large cutter suction dredges, such as those used at Chek Lap Kok airport or the Öresund Fixed Link (see Section 2.1), can excavate a variety of materials. While the plant operating cost is high, in certain conditions these dredges can move and place material for under US$1.00 per cubic meter. Additional savings could be achieved if the spoil is used beneficially. Sale of good fill and land reclamation are possible uses.

4.2 Dry Excavation Techniques

The disposal location and topography and the material types will be the keys to determining the most appropriate dry excavation techniques. Large bucket excavators working in conjunction with large off-highway trucks can offer very low excavation unit costs. The character of the material and the route of the haul road will determine the number and size of each. In the hilly forest surrounding many of the alignments, the largest vehicles may not be the most economic. Heavy rainfall will necessitate the construction of an all weather road. Utilizing smaller trucks could reduce this cost since they require smaller roads.

Careful attention should be given to the presence of any hazardous or other material requiring special disposal in the alignments. Such materials require special excavation and disposal techniques. Excavation and disposal costs of such materials may be well over an order of magnitude higher than standard excavation costs. Thus the character of the material to be excavated could play a bigger role than the quantity in determining the most cost-effective alignment and technique.

5.0 CONCLUSIONS AND RECOMMENDATIONS

A variety of excavation techniques may be employed in the construction of the proposed new alignments. In general, all alignments would require a combination of both dry and wet excavation. The type of equipment employed will depend on the final quantity and character of the materials to be excavated. Exhibit 1 provides a matrix of applications for equipment excavating various material types.

Both dry and wet excavation in the proposed alignments will benefit from improved technology. Real time kinematic GPS technology now allows excavation to proceed with great precision in both dry and wet situations. Larger land-based and floating equipment offer greater efficiency and lower costs on massive excavations such as that required for the new locks.

The Gaillard Cut widening program offers evidence that contracting out dry excavation is both cost-effective and efficient for the ACP. If contracts are grouped into larger quantities, economies of scale could reduce the unit prices. A multimillion cubic meter excavation contract would warrant the purchase or lease of larger, more efficient equipment for excavation and hauling (see Appendix B).

A similar approach could reduce the cost of underwater excavation as well. Grouping wet excavation into a few large dredging contracts could reduce unit costs and attract the world's most efficient equipment. In particular, large cutter suction and backhoe dredges currently available could offer competitive costs and attractive schedules. Working simultaneously with the ACP equipment, modern jumbo dredges could speed project completion and offer cost savings.

Finally, spoil from both wet and dry excavation has many potentially beneficial uses. Spoil may be used within the project as fill for dams or to create platforms for new ancillary structures. High quality rock will also provide aggregate for the new concrete guidewalls and locks. Excavated rock could be used to reinforce and expand the Amador Causeway. Local contractors and developers may purchase spoil for fill or aggregate. Also, after environmental evaluation, the overburden may be useful for filling in low-lying areas or to create wetlands habitats.

COMPARISON OF EXCAVATION EQUIPMENT

Rating	1	2	3
Efficiency	Best-Suited	Suitable	Not Appropriate

Equipment	Soil Type				
	Sound Rock*°	Weathered Rock*	Blasted Rock	Compacted Soils	Loose Soils
Wet Excavation					
Mechanical					
Dipper Dredge	1	1	1	1	1
Backhoe Dredge	1	1	1	1	1
Clamshell Dredge	3	3	2	2	1
Land-based Backhoe	2	1	1	1	1
Hydraulic					
Suction Dredge	3	3	3	3	1
Cutter Suction Dredge	2	1	1	1	1
Trailing Suction Dredge	3	3	3	2	1
Dry Excavation					
Excavation					
Scraper	3	3	3	1	1
Holland Loader	3	3	3	1	1
Hydraulic Shovel	2	1	1	1	1
Wheel Loader	1	1	1	1	1
Transport					
On Road Truck	3	3	3	1	1
Off Road Truck	1	1	1	1	1
Conveyor	3	3	3	1	1

*In dry conditions, rock must be ripped by a tractor prior to excavation.
• Up to 40 Mpa (5,800 psi).

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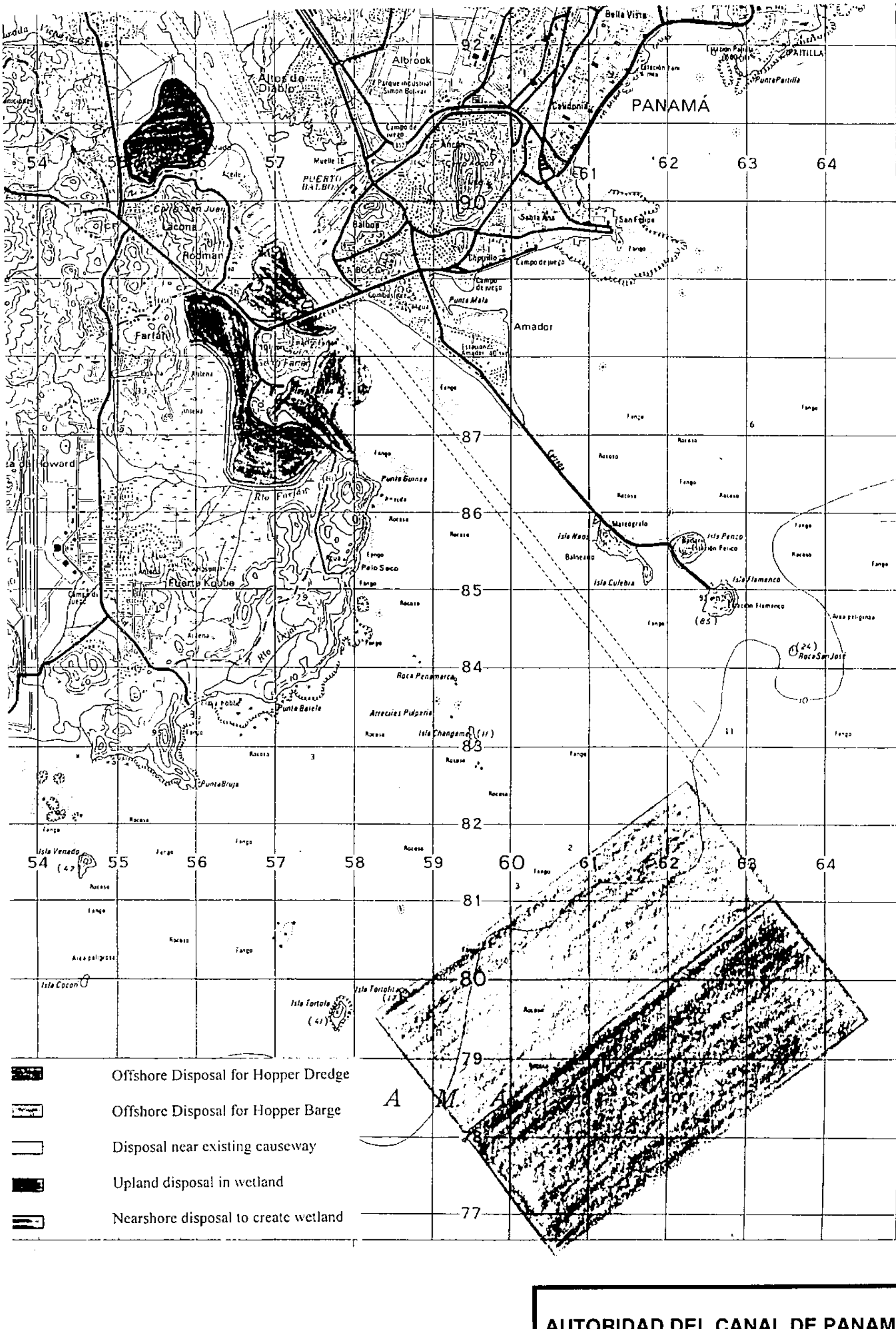
Review of Excavation Methodologies
Comparison of Excavation Equipment

HARZA TAMS	August 2000	Exhibit 1



Note: Not to Scale.

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EVALUATION OF LOCK CHANNEL ALIGNMENTS
Review of Excavation Methodologies
Potential Disposal Sites for Pacific Entrance

HARZA TAMS	August 2000	Exhibit 2

THE PANAMA CANAL
EVALUATION OF LOCK CHANNEL ALIGNMENTS
PART 4 – REVIEW OF EXCAVATION METHODOLOGIES

APPENDIX A

WET EXCAVATION EQUIPMENT

THE PANAMA CANAL
EVALUATION OF LOCK CHANNEL ALIGNMENTS
PART 4 – REVIEW OF EXCAVATION METHODOLOGIES

APPENDIX A
WET EXCAVATION EQUIPMENT

TABLE OF CONTENTS

EXHIBITS

EXHIBIT A-1

POTENTIAL EQUIPMENT LISTS – WET EXCAVATION

Potential Equipment List - Wet Excavation

HYDRAULIC DREDGES

Name	Owner	Discharge Dia. (mm)	Installed Power kW	Hp
Leonardo da Vinci	Jan de Nul	900	20,250	27,145
Marco Polo	Jan de Nul	900	16,115	21,602
Ursa	Boskalis	900	15,830	21,228
Castor	Ballast Needam	850	15,221	20,403

TRAILING SUCTION DREDGES

Name	Owner	Hopper Capacity (CM)	Installed Power kW	Hp
Vasco de Gama*	Jan de Nul	33000	36,940	49,517
Fairway	Boskalis	23347	27,500	36,863
Amsterdam	Ballast Needam	18000	22,000	29,491
Lelystad	Ballast Needam	10330	15,725	21,079

*Under construction

BACKHOE DREDGES

Name/Type	Owner	Bucket Size (CM)	Installed Power kW	Hp
New York	Great Lakes	19	2,565	3,438
Rocky	Boskalis	N/A	1,230	1,649
Manu-Pekka	Boskalis	14	840	1,126
Jerommeke	Jan De Nul	11	736	987

EXHIBIT A-2

MECHANICAL DREDGES

Rialto M Christensen

GENERAL
Name Rialto M Christensen
Owner Panama Canal Commission
Marine Manager Panama Canal Commission
Year Built 1977
Builder The Hakodate Dock Co Ltd., Japan
Type Dipper Dredger
Flag Panama

MAIN DIMENSIONS
LOA 49.99 m **Breadth** 21.5 m **Depth** 4.8 m
GRT 3692 t **Draft** 3.29 m

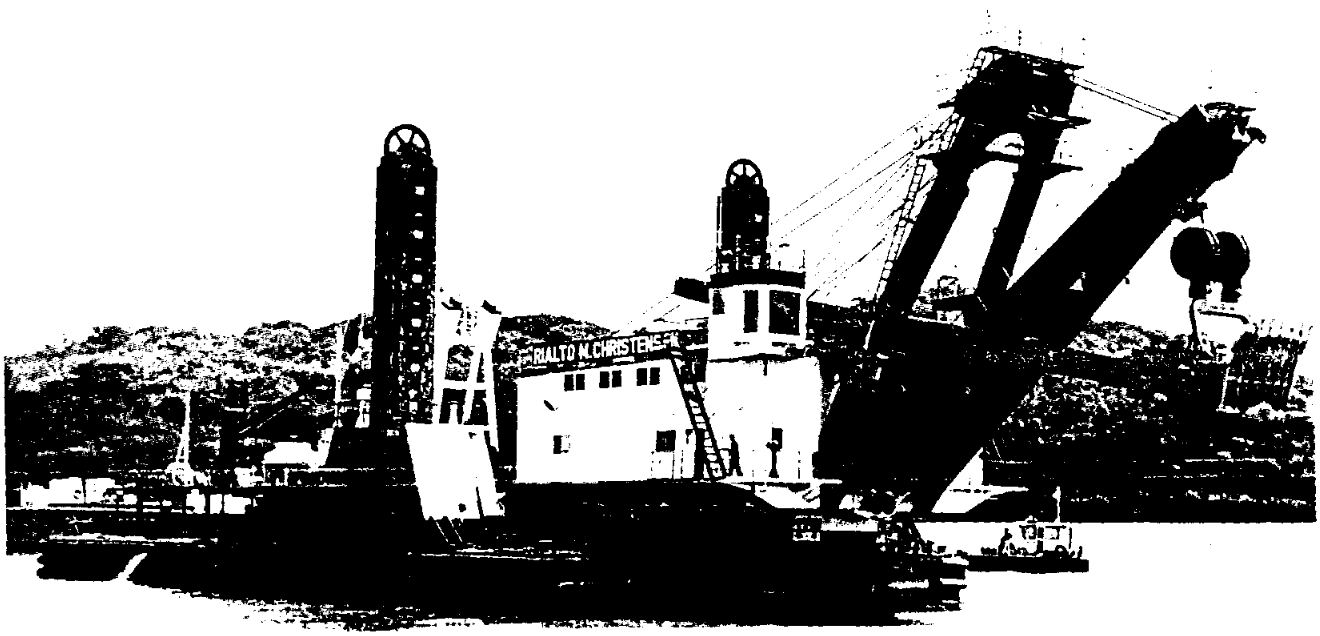
MACHINERY AND POWER
Main Engines Main generator sets: Fuji diesel engine, 4-cycle, single acting, direct injection, exhaust turbo-charged, 2150bhp at 600rpm. Shinko Electric generator: 1 x AC 800kW, 445V AC, 600rpm, 60Hz; 1 x DC 600kW, 750V, 600rpm.

OPERATING PARAMETERS
Dredging Depth Normal 18.3 m

DREDGING AND DISCHARGING EQUIPMENT
Grab/Backhoe Capacity 11.5 m3

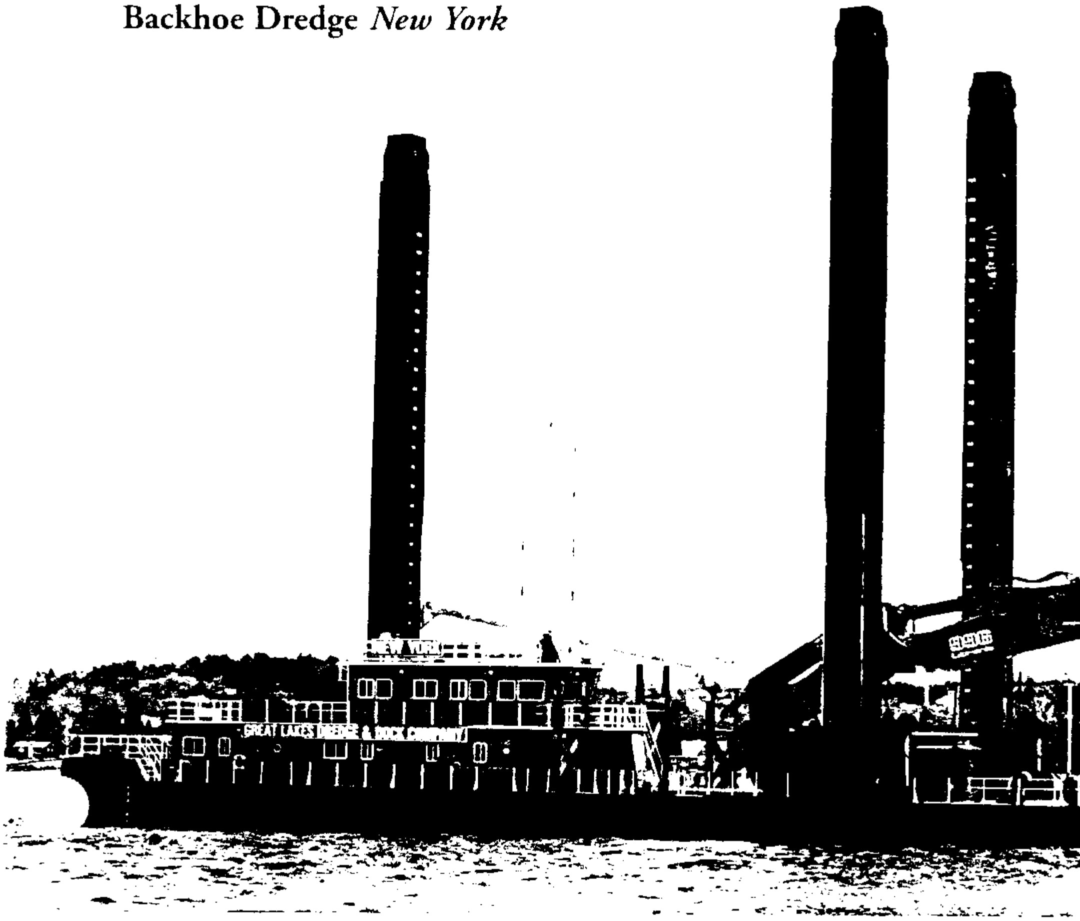
MOORING AND POSITIONING SYSTEMS
Fore and aft spuds.

ADDITIONAL DATA
1. Auxiliary generator set: Yanmar diesel engine, vertical, 4-cycle, single acting diesel engine, 160bhp at 900rpm. Yanmar diesel engine, 100kW, AC 445V, 900rpm, 60Hz, 3-phase. 2. Positioning equipment. Motorola Falcon IV, 01-PO 6841Y001. Sperry gyro-compass system; digital repeater. 3. 3 x air compressors. 4. Dumping radius: 18-22m; Dumping height: 6.5m; Dumping range (slewing angle): 180 degrees. Dredging range: 90 degrees; Slewing speed (at outreach of dumping of 18m): 1.5rpm; Main hoisting and boom luffing winch: 60/160t x 80/25 m/min; Dipper handle thrust winch: 32/80t x 25/5.5 m/min, 2 x fore spud winches 90/160t x 10/5m/min; aft spud winch: 40t x 6m/min.



Launched — December 20, [illegible]
Outfitting Completed — May [illegible]

Backhoe Dredge *New York*



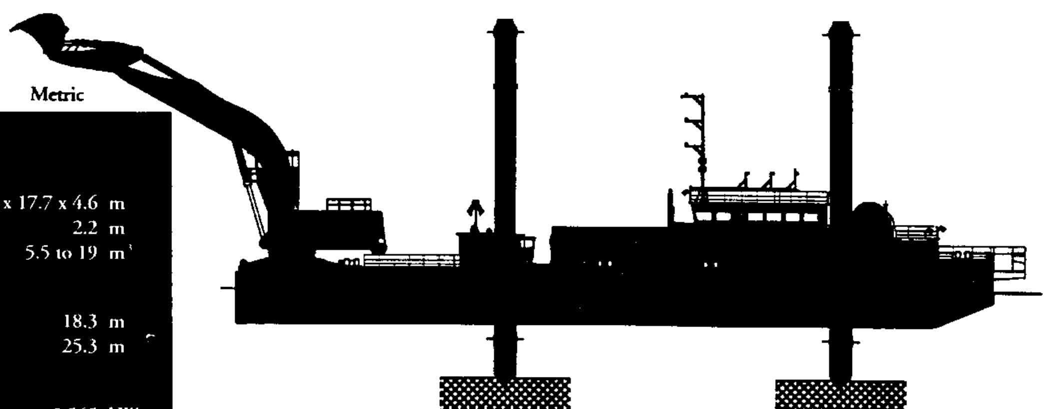
The New York *in drydock at Bay Shipbuilding Co. in Sturgeon Bay, Wisconsin.*

Continuing Investment: *The Dredge* New York *is the forty-fourth vessel built for Great Lakes Dredge & Dock Co. by Bay Shipbuilding Co. and its parent company, Manitowoc Marine Group, Inc. It is the largest backhoe dredge in the world; will dig in mud with a 25-yd³ bucket, with a 17-yd³ bucket in firmer materials, and a 15-yd³ bucket in hard materials.*

SPECIFICATIONS

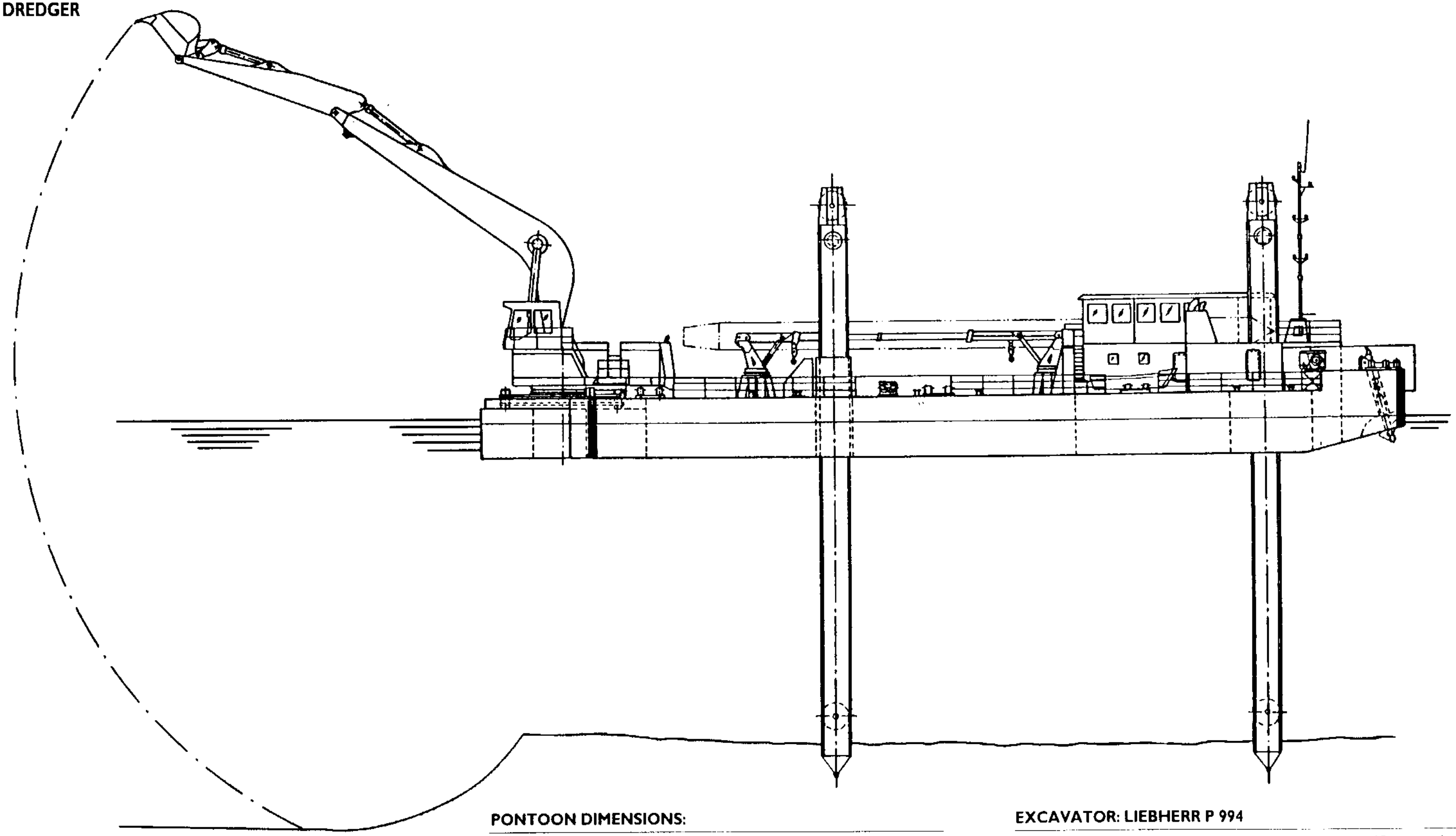
Backhoe Dredge *New York*

	Imperial	Metric
Dimensions		
Hull	200 x 57 x 15 ft	62 x 17.7 x 4.6 m
Draft (Light, excavator aft)	7 ft	2.2 m
Bucket Capacity	7 to 25 yd³	5.5 to 19 m³
Performance		
Digging Depth, Nominal	60 ft	18.3 m
Digging Depth, Maximum	83 ft	25.3 m
Power Data		
Total Installed Power	3,434 hp	2,565 kW
Fuel Capacity	60,000 gal	228,000 l



JEROMMEKE

BACKHOE DREDGER



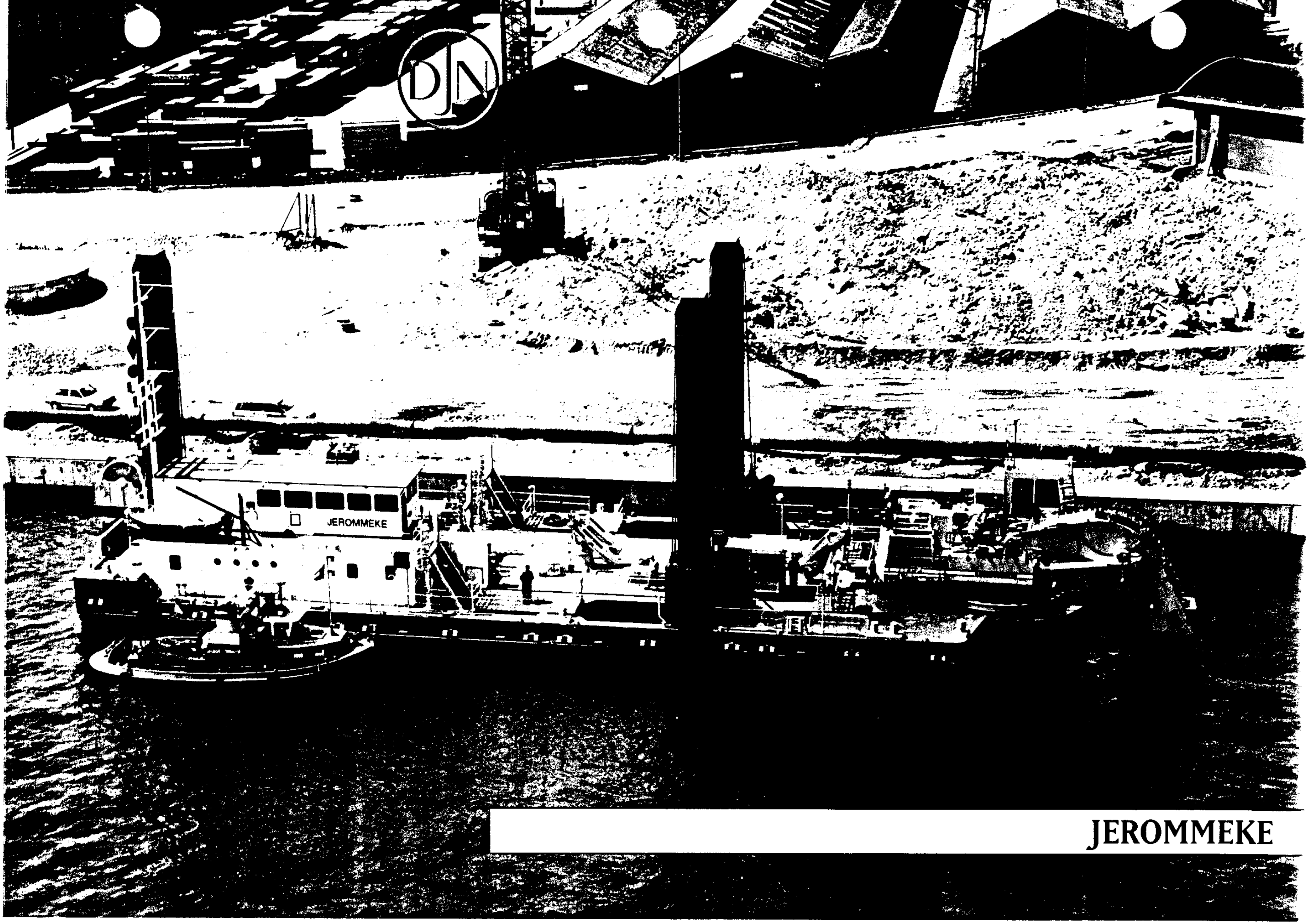
PONTOON DIMENSIONS:

Length	45,0 m
Breadth	15,0 m
Draught	2,0 m
Class	coastal service

EXCAVATOR: LIEBHERR P 994

Max. dredging depth	18 m (standard)
	22 m (optional)
Bucket	4,5 to 11,0 m³
Engine	736 kW

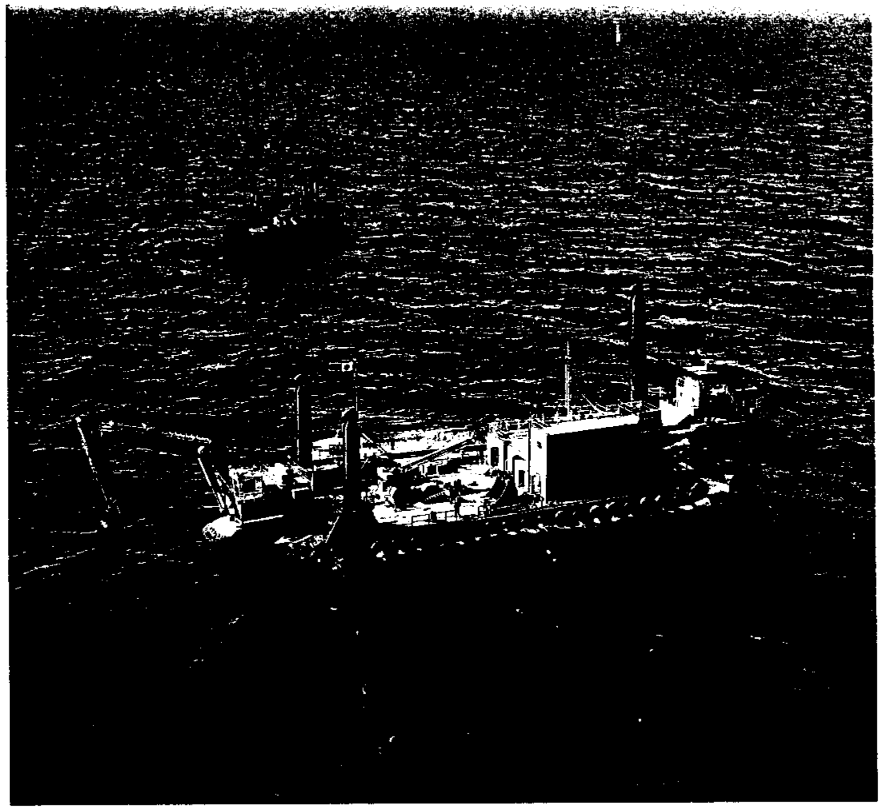
HEAD OFFICE BELGIUM JAN DE NUL N.V. Tragel 23, B-9308 HOFSTADE-AALST - Phone : 32.53.73.15.11 - Fax : 32.53.78.17.60 / 32.53.77.28.55 - Telex : 12340



JEROMMEKE

MANU-PEKKA

Backhoe dredger



FEATURES

- Can work upto 15 miles offshore.
- Equipped with a computerised excavation monitoring system, a DGPS/RTK system and a VHF-radio.

MAIN DATA

Built by	OMP Oy, Finland
Year of contruction	1983/96
Classification	B.V. I 3/3 (-) Deep Sea
Tonnage	680 RT
Length overall	47.93 m
Width	15.00 m
Moulded depth	3.07 m
Draught	2.00 m
Maximum dredging depth	18.50 m
Maximum water depth for spuds	23.00 m
Bucket sizes	4.5 - 14 m^3
Crane	Demag H 185 S (1996)
Hull	Welded steel

Royal
Boskalis Westminster nv

International Dredging Contractors

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3350 AA Papendrecht, The Netherlands
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Telex 29012

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EXHIBIT A-3

HYDRAULIC DREDGES

Mindi

GENERAL
Name Mindi
Owner Panama Canal Commission
Marine Manager Panama Canal Commission
Year Built 1943
Builder Ellicott Machine Corporation, Maryland, USA
Conversion/Refit Year 1986
Type Cutter Suction Dredger
Flag Panama

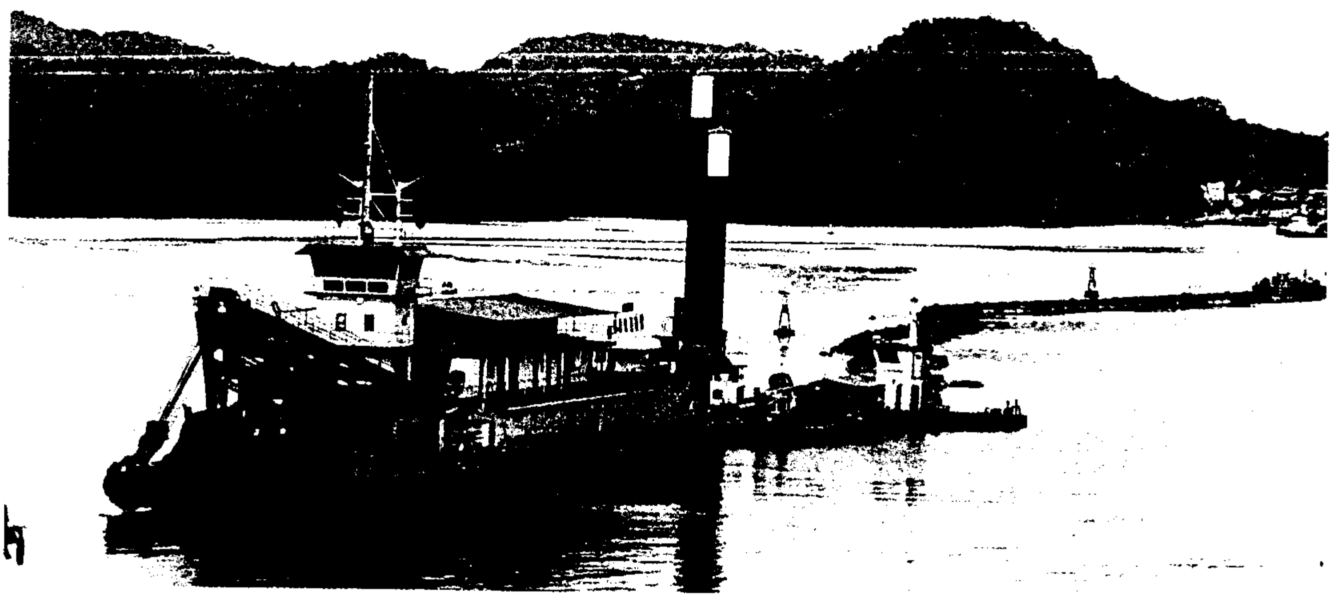
MAIN DIMENSIONS
LOA 120.5 m **Breadth** 15.75 m **Depth** 4.27 m
Draft 3.35 m

MACHINERY AND POWER
Main Engine(s) 2 x EMD 645-S-20-E4. 3600hp, 900rpm coupled through Eaton air clutches and Horsburgh & Scott 270-S vertical offset reduction gears (2.75 -1).
Cutter Electric 745 kW
Dredge Pump(s) 2 x Diesel/Electric
Inboard Pump(s) Electric ladder pump **total capacity** 671 kW

OPERATING PARAMETERS
Dredging Depth Normal 21.95 m

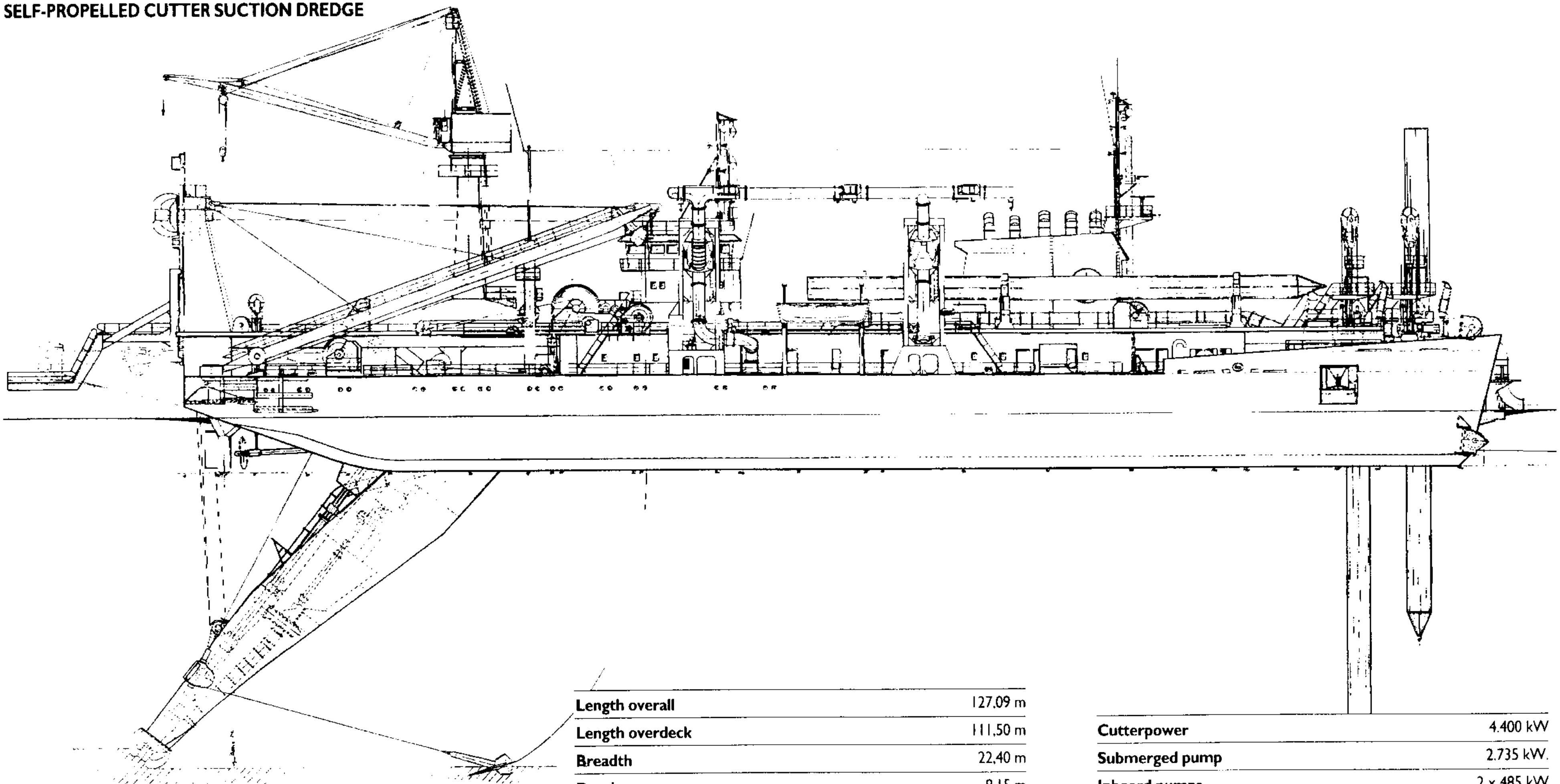
MOORING AND POSITIONING SYSTEMS
Mooring System Spuds.
Spud System Carrier

ADDITIONAL DATA
1. LOA above is measured outside of spud barge to end of cutter with ladder horizontal. Length moulded:67.67m. 2. Spud barge dimensions: 30.48m x 15.24m x 4.27m (draft). 3. Displacement: 5710 tons (spuds up, ladder up, oil and water tanks full, with spud barge connected). 4. Auxiliary power: 2 x Lima generators, 300kW each, 3-phase, 60-cycles, 288/480V at 1800rpm, driven by Cummins diesel engines type KTA-1150, in-line 6, 425hp at 1800rpm. Power units: 3 x generators, EMD AB20-24, 1180kW at 900rpm, 2400V AC, driven by diesel engine 12-645E8 V12, 1500hp at 900rpm. 5. Vessel conversions: 1977-1979 - Vessel repowered/converted in house from steam to diesel/electric; new ladder pump, generator, dredge main pumps and auxiliary power installed. 1980-1982 - Main drive reduction gears modified; sound barriers and oilers booths installed. 1984-1986 - Installation of 2 x EMD generators, new cutter drive, 3 new winches for dredge operation, modernization of spud carriage system and SCR system and replacement of lever house.



LEONARDO DA VINCI

SELF-PROPELLED CUTTER SUCTION DREDGE



Length overall	127,09 m
Length overdeck	111,50 m
Breadth	22,40 m
Depth	8,15 m
Draught	5,18 m
Dredging depth	32,00 m
Suction pipe diameter	900 mm
Discharge pipe diameter	900 mm
Barge-loading pipes diameter	900 mm

Cutterpower	4.400 kW
Submerged pump	2.735 kW.
Inboard pumps	2 x 485 kW
Propulsion	2 x 2.735 kW
Total installed diesel engine power	20.250 kW
Speed	11 Kn
Complement	41 persons
Built in	1986

DCR
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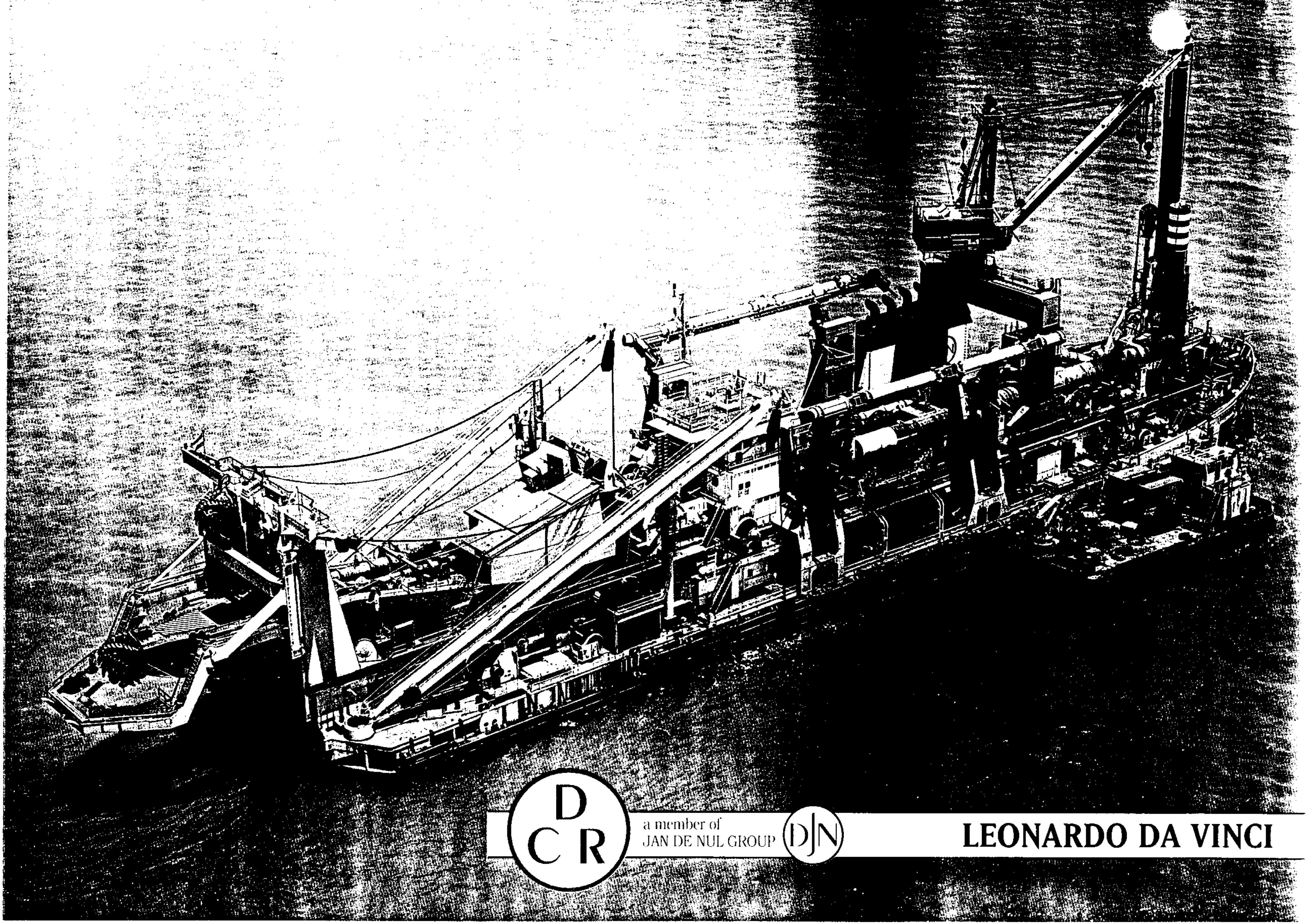
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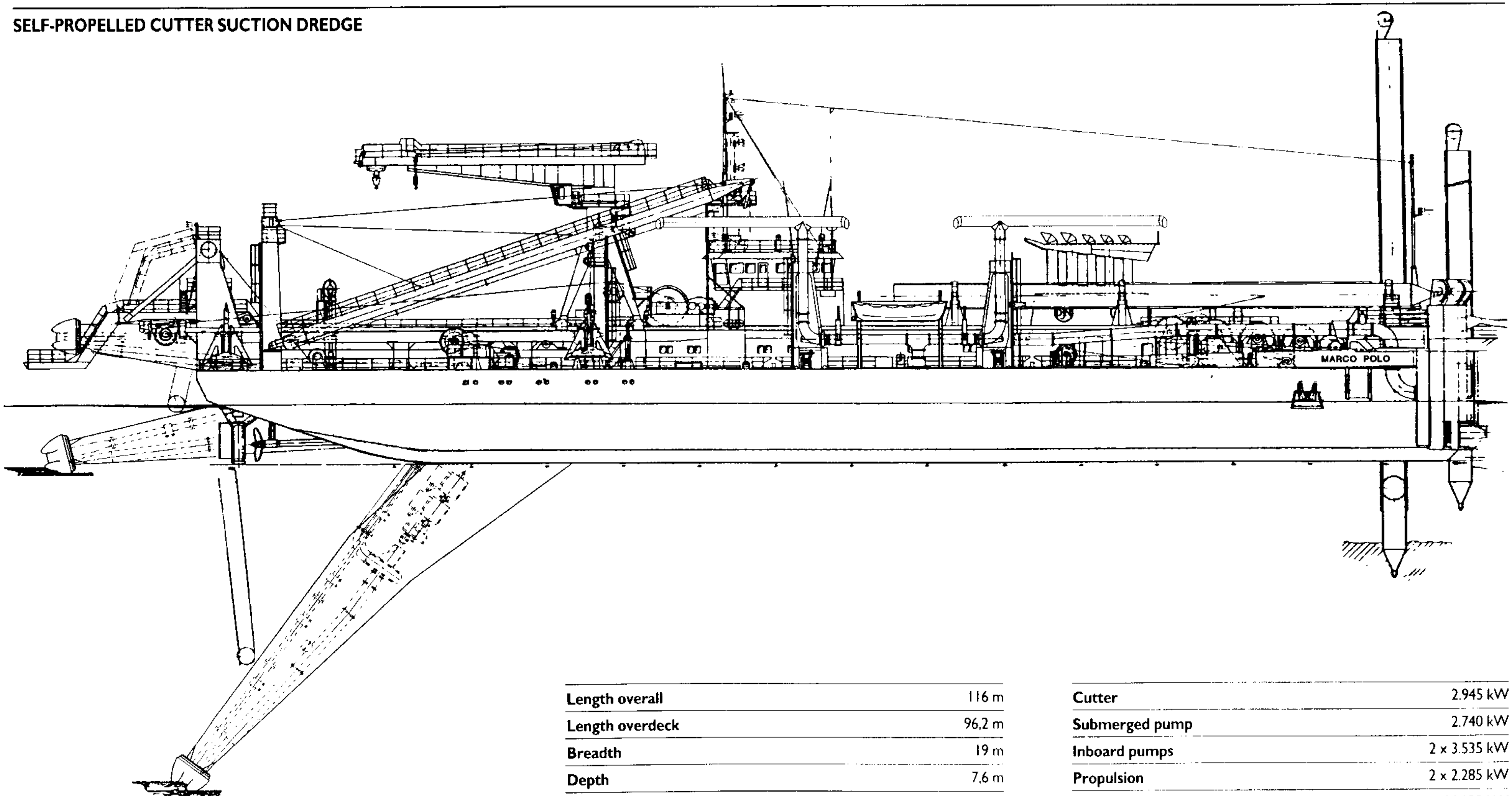
DJN
LEONARDO DA VINCI

MARCO POLO

SELF-PROPELLED CUTTER SUCTION DREDGE

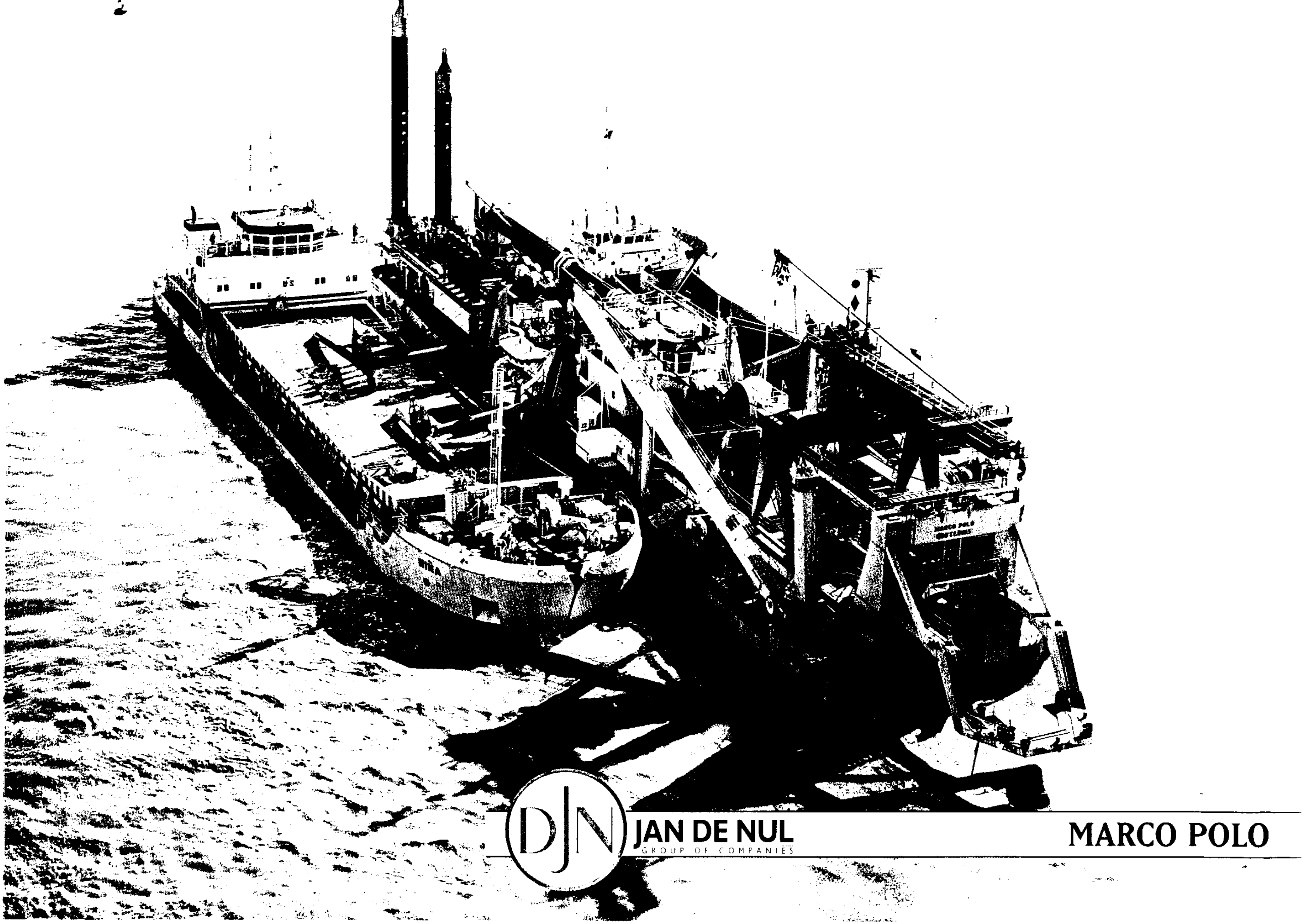


Length overall	116 m
Length overdeck	96,2 m
Breadth	19 m
Depth	7,6 m
Draught	4,6 m
Dredging depth	30 m
Suction pipe diameter	900 mm
Discharge pipe diameter	900 mm
Barge-loading pipes diameter	750 mm

Cutter	2.945 kW
Submerged pump	2.740 kW
Inboard pumps	2 x 3.535 kW
Propulsion	2 x 2.285 kW
Total installed diesel engine power	16.130 kW
Speed	11 Kn
Complement	45 persons
Built in	1979

DJN JAN DE NUL
GROUP OF COMPANIES

HEAD OFFICE BELGIUM Tragel 23, B-9308 HOFSTADE-AALST - Tel. : Nat. Division : 32.53.73.15.11, Intl. Division : 32.53.73.17.11 - Telefax : 32.53.78.17.60 - 32.53.77.28.55 - E-mail : info@jandenul.com - Website : www.jandenul.com


JAN DE NUL
GROUP OF COMPANIES
MARCO POLO

CASTOR

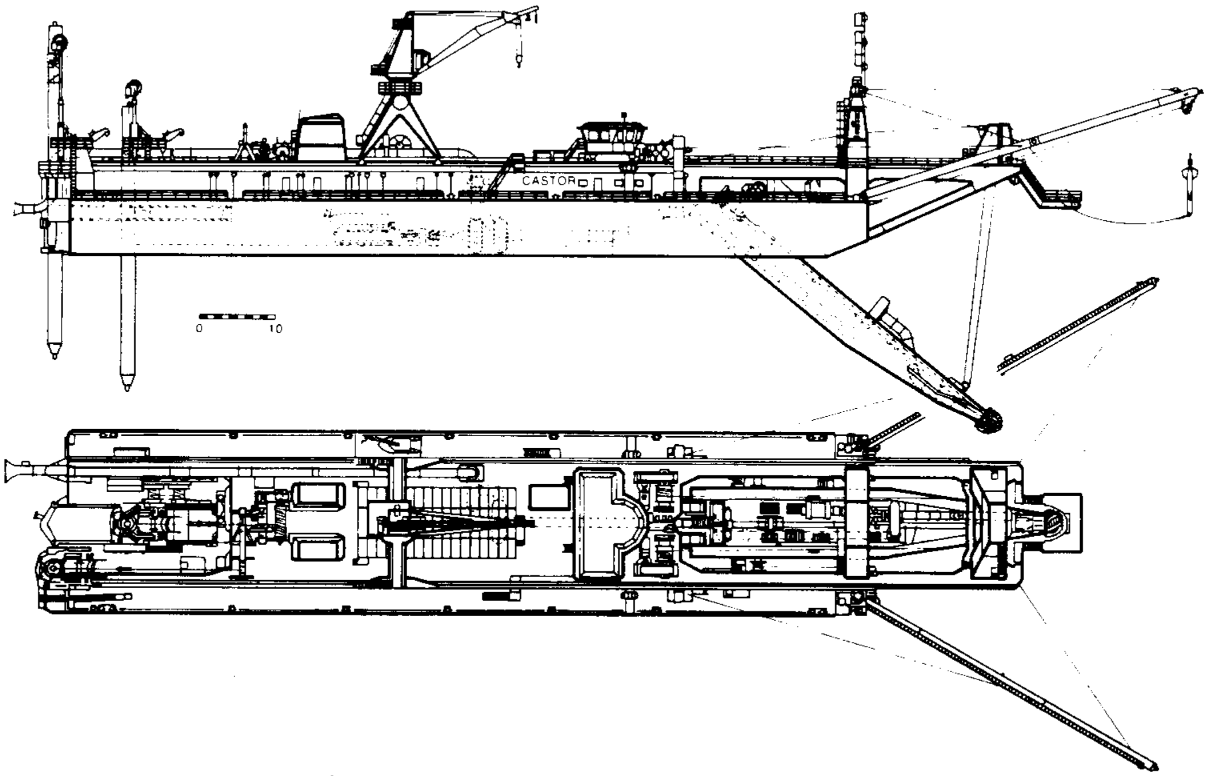
Cutter suction dredger

Principal particulars

Length overall	110.68 m
Length of hull	78.50 m
Breadth	18.00 m
Moulded depth	5.50 m
Draught	4.00 m

Total machinery output	15,221 kW
Dredge pumps	2 x 2,800 kW
Underwater pump	1,765 kW
Jet pump	710 kW
Cutter	3,680 kW

Class:	Bureau Veritas ✠ I 3/3 Dredger NP Deep Sea
Suction pipe	Ø 850 mm
Discharge pipe	Ø 850 mm
Dredging depth	25 m with extension 33 m



Ballast Nedam Dredging

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The Netherlands

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Telefax + 31 30 6947900
e-mail pr@bnd.nl

With the commissioning of the cutter suction dredger CASTOR in 1984, a leading position within the dredging industry was again established.

The 15,221 kW dredger is among the most powerful in the world and embodies the latest in technology. With her 3,680 kW cutter drive power and a cutter ladder weight of 600 tons, she has been designed and built to operate in hard soils.

The computerized dredging process enables the dredge master to make optimum use of the available power. The CASTOR is highly sophisticated and can dredge slopes etc. fully automatically. An extension piece can be mounted to the ladder to reach a depth of 33 m.

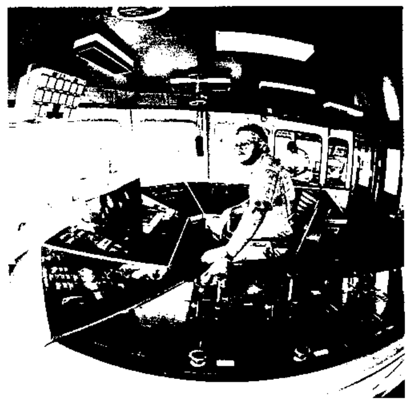
1. Deepening berth for bulk carriers

2. Computerised operation room

3. Workplatform for replacing cutterteeth and changing cutters

4. The CASTOR dredging rock

2



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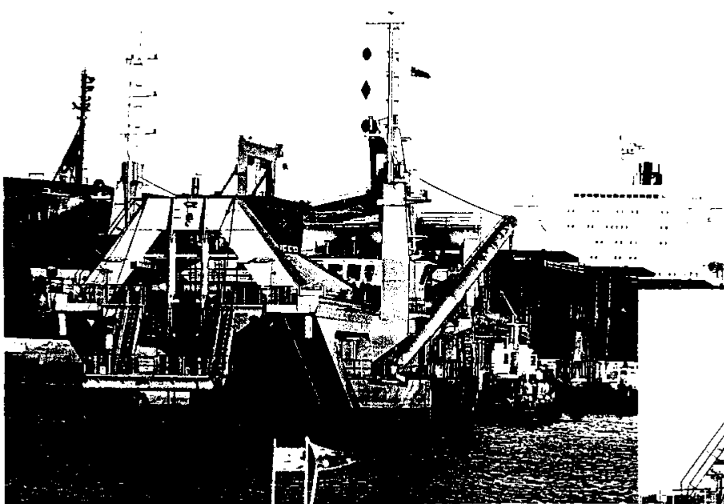

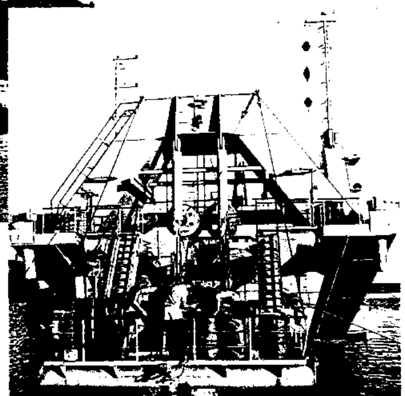

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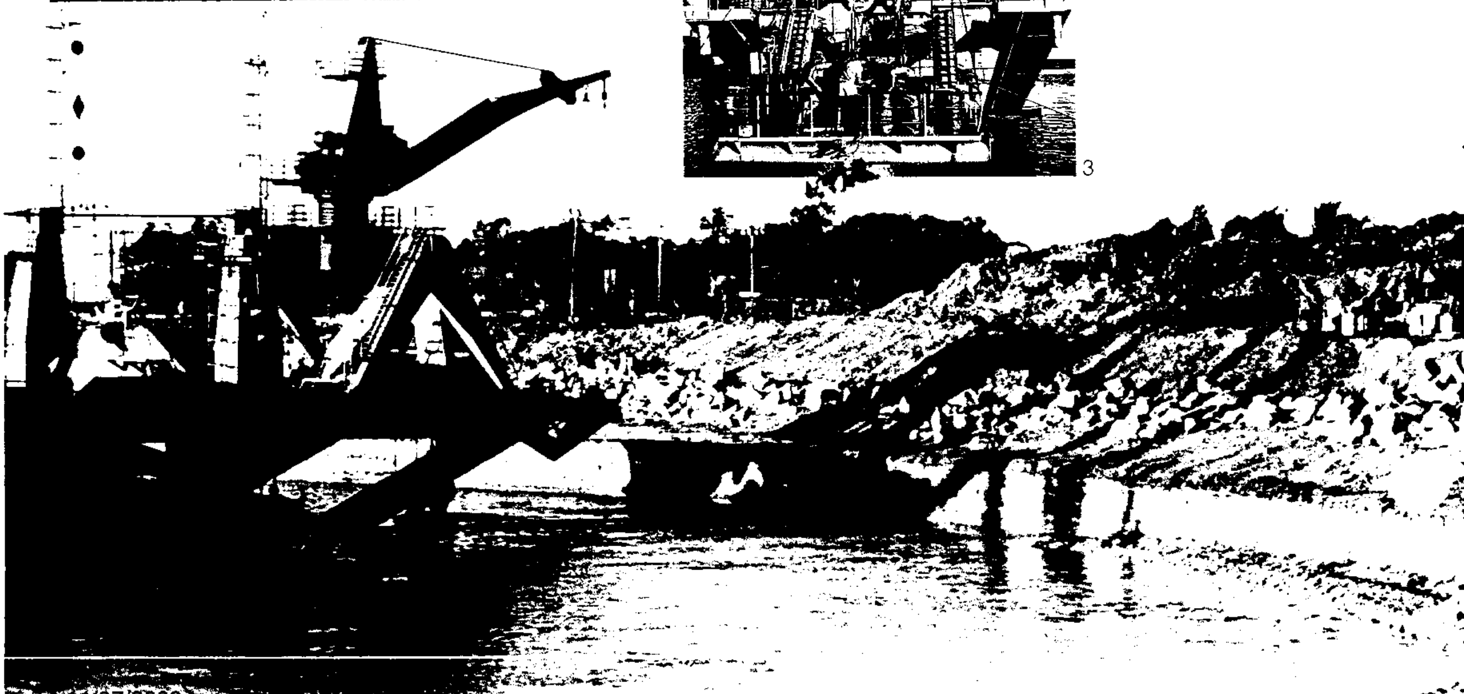
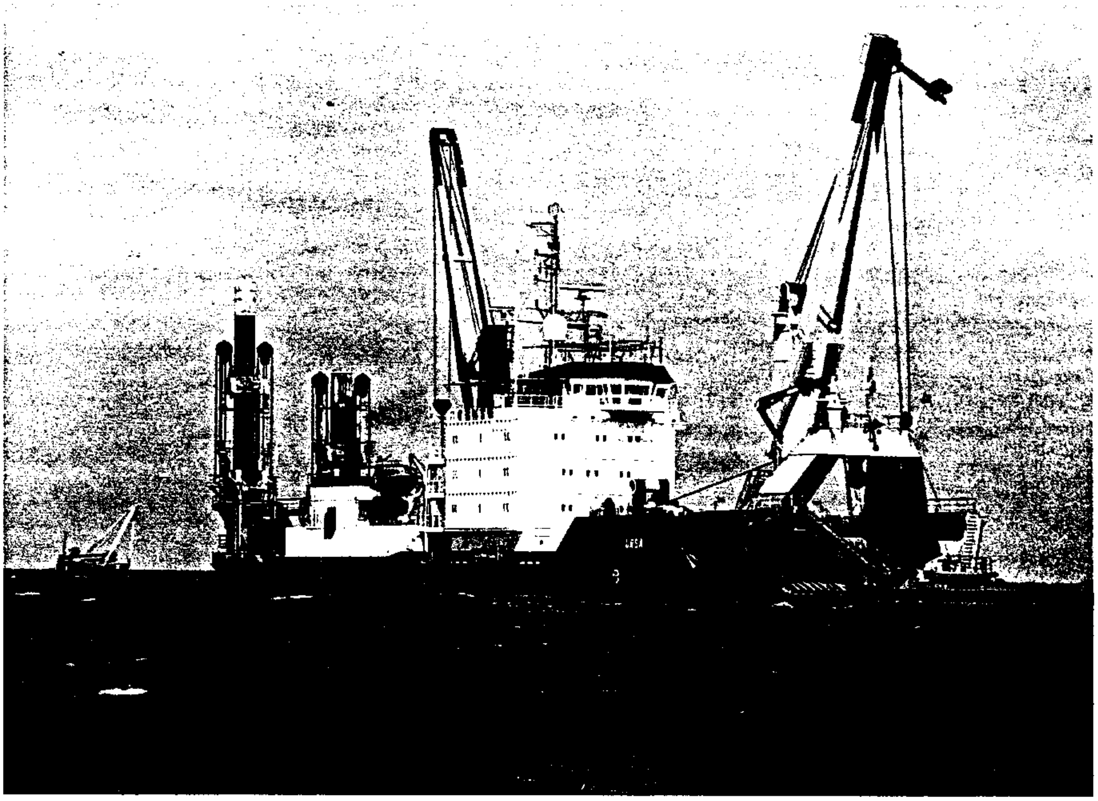


URSA

Cutter suction dredger

FEATURES

- A heavy duty rock cutting sea going self-propelled dredger designed for operations in sheltered and coastal waters up to 15 miles offshore.
- Equipped for working in hot, tropical climates and isolated locations.
- Fully automated dredging process centrally controlled.



MAIN DATA

Built by	Orenstein & Koppel
Year of construction	1986
Classification	G.L. 100 A4 E3
Tonnage	3,877 GT / 1,163 NT
Length overall	105.43 m
Length hull	92.59 m
Width	20.00 m
Moulded depth	7.80 m
Maximum draught	5.64 m
Suction pipe diameter	950 mm
Discharge pipe diameter	900 mm
Maximum dredging depth	25.00 m
Minimum dredging depth	5.50 m
Anchoring system	spud carriage
Total installed power	15,830 kW (21,523 mhp)
Cutter output	3,300 kW (4,487 mhp)
Suction pump output	2,200 kW (2,990 mhp)
Discharge pump output	2 x 3,700 kW (2 x 5,030 mhp)
Propulsion engines	2 x 3,700 kW (2 x 5,030 mhp)

Royal Boskalis Westminster nv

International Dredging Contractors

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EXHIBIT A-4

TRAILING SUCTION HOPPER DREDGES

Trailing suction hopper dredgers

Queen of the Netherlands

Name:
Queen of the Netherlands

Type:
Trailer

Hopper capacity:
23,350 m³

Features
Vessel's hopper size provides significant economies of scale. A service speed of 17 knots, powerful pumps and advanced technology for fast and accurate dredging.

Highly manoeuvrable and designed for both shallow and deep water operations, with three hopper discharge options.

Innovative features will safeguard marine environment.

Dynamic Positioning (DP and Dynamic Tracking (DT) ensure optimum control of the vessel and draghead, resulting in precise and efficient dredging techniques.

High quality specification, comprehensive safeguards and experienced, professional crew ensure operational safety.

Main Data

Built by	Verolme, Heusden
Year of construction	1998
Length	173.5 m
Breadth	32.00 m
Depth moulded	13.10 m
Dredging draught	12.95 m
Deadweight at dredging mark	32,100 dwt
Total installed power	27,600 kW
Propulsion	2x10,000 kW
Bow thruster	1,400
Bow jet	1,000
Service speed	16.7 knots
Hopper capacity	23,350 m^3
Dredge pumps	2x6,000 kW
Shore discharge pump capacity	12,000 kW
Jet pumps	3x1,000 kW
Suction pipes (diameter)	1,200 mm
Max. dredging depth	120 m

Back

AMSTERDAM

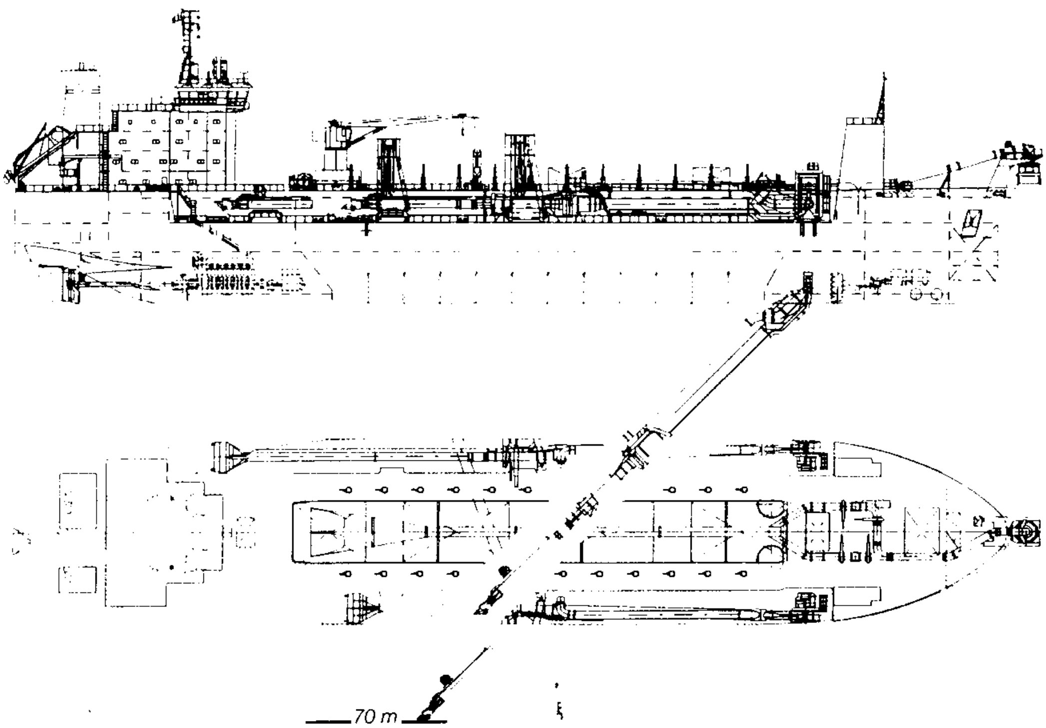
Trailing suction hopper dredger

Principal particulars

Length overall	156.00 m
Breadth	28.00 m
Moulded depth	11.85 m
Draught (loaded)	10.00 m
Gross tonnage	18,260
Service speed	15 knots

Total machinery output	22,000 kW
Propulsion	2 x 7,000 kW
Bow thruster	2 x 750 kW
Dredge pumps	2 x 5,200 kW
Submerged dredge pumps	2 x 1,800 kW
Waterjets draghead	2 x 1,275 kW

Class:	Bureau Veritas ✠ I 3/3
Hopper dredger / Deep Sea AUT-MS	
Hopper capacity	18,000 m^3
Suction pipe	2 x Ø 1,100 mm
Pump ashore pipe	Ø 1,000 mm
Dredging depth	70 m



Ballast Nedam Dredging

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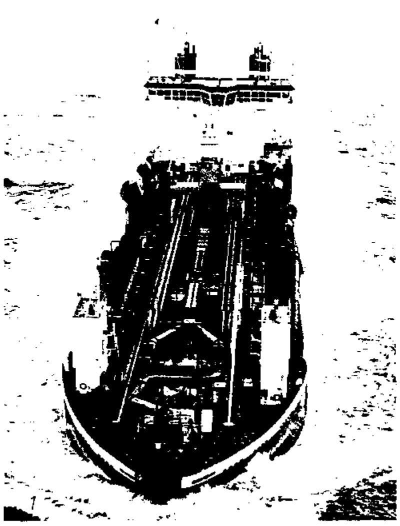
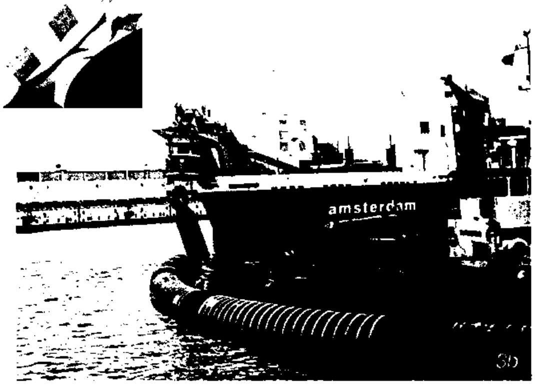
The newest and largest trailing suction hopper dredger operated by the Ballast Nedam Dredging Group, called 'AMSTERDAM', was built in 1996 under Bureau Veritas classification I 3/3 hopper dredger deep sea AUT-MS. This relatively shallow draught dredger can discharge the dredged material by dumping through conical bottom valves, by pumping ashore over the bow or by accurate placing on the seabed by reverse pumping through the suction pipes. This new vessel is equipped with state of the art communications, navigation and positioning systems with real time transfer of data to and from shore stations and/or survey vessels.

Also installed are:

- High degree of automation and computerisation of dredging and propulsion systems
- Electrical directly driven underwater pumps in both suction pipes
- Dynamic Positioning (DP) system
- Autotrack system, which in combination with DP and DGPS will enable the vessel to dredge accurately along predetermined tracks and dump exactly at the required locations.
- Multi-beam echosounding system hull-mounted in the forward section of the vessel provides on-line 3-dimensional display and mapping information of the seabed ahead of the vessel.

The seabed visualisation system provides highly detailed information of the seabed. Fast processing of the sounding data ensures real-time digital terrain modelling.





1. Sailing to the offshore dumping area

2. The operations desk

3. Connecting the discharge pipe

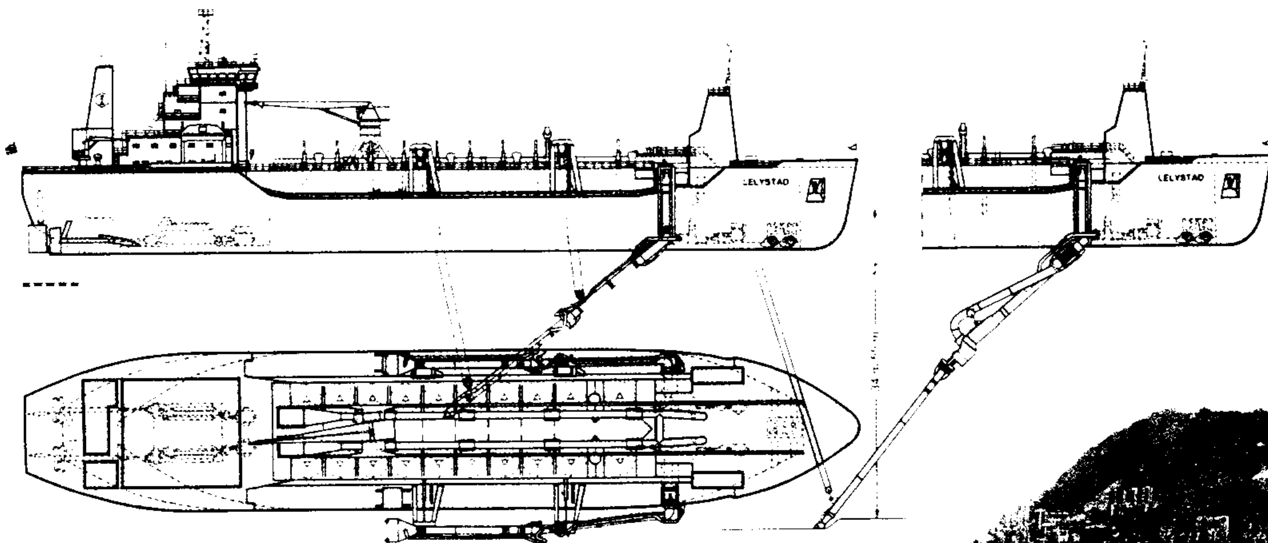
4. Pumping sea sand ashore in the Indiahafen, Hamburg

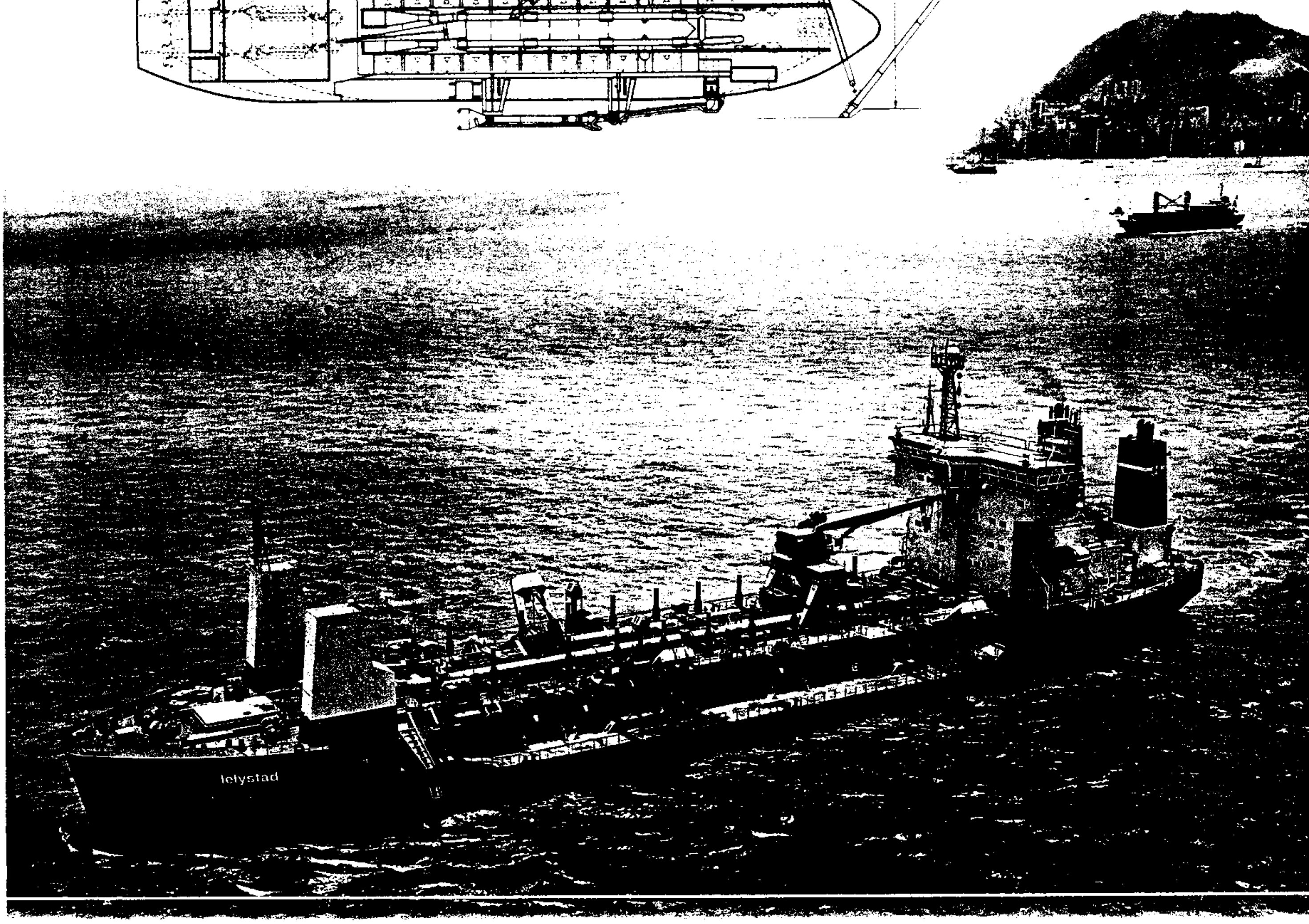
LELYSTAD

Trailing suction hopper dredger

Principal particulars

Length overall	137.00 m	Total machinery output	15.725 kW	Class:	Bureau Veritas ✠ I3.3
Breadth	26.00 m	Propulsion	10.370 kW		Hopper dredger Deep Sea
Moulded depth	8.80 m	Bow thruster	2 x 375 kW	Hopper capacity	10.330 m
Draught	8.00 m	Dredge pumps	2 x 1.850 kW	Suction pipes	2 x Ø 1.200 mm
Gross tonnage	12.116	Submerged		Dredging depth	55 m
Service speed	15.2 kn	dredge pumps	2 x 900 kW		with extension 70 m
		Waterjets draghead	2 x 660 kW		





Ballast Nedam Dredging

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The trailing suction hopper dredger LELYSTAD was built under Bureau Veritas classification I 3/3 Hopper Dredger Deep Sea AUT-MS. With a hopper capacity of 10,330 cubic metres the LELYSTAD belongs to the upper class of medium size trailers. Equipped with state of the art automated dredging & navigation systems and large-diameter underwater pumps installed in both suction pipes, she is capable of dredging most efficiently at depths in excess of 55 metres. A large number of projects have kept the vessel occupied virtually continuously since her commissioning in 1987, proving her capabilities equally well in the tropical seas of Brazil, India and Malaysia as well as in the rough winter conditions of the icy North Sea. In 1992 underwater pumps were installed and the suction pipes were lengthened to carry out deep dredging for winning fill materials, seabed levelling and trenching for pipelines. If required, modifications allow dredging beyond 70 metres depth. Since then the LELYSTAD has produced up to 100,000 m per day from 55 metres depth in Hong Kong waters for the Container Terminal no. 8 and the new airport reclamation project at Chek Lap Kok.

1. *Lowering the suction pipe*
2. *Cleaning the draghead*
3. *The LELYSTAD in the Port of Hong Kong*

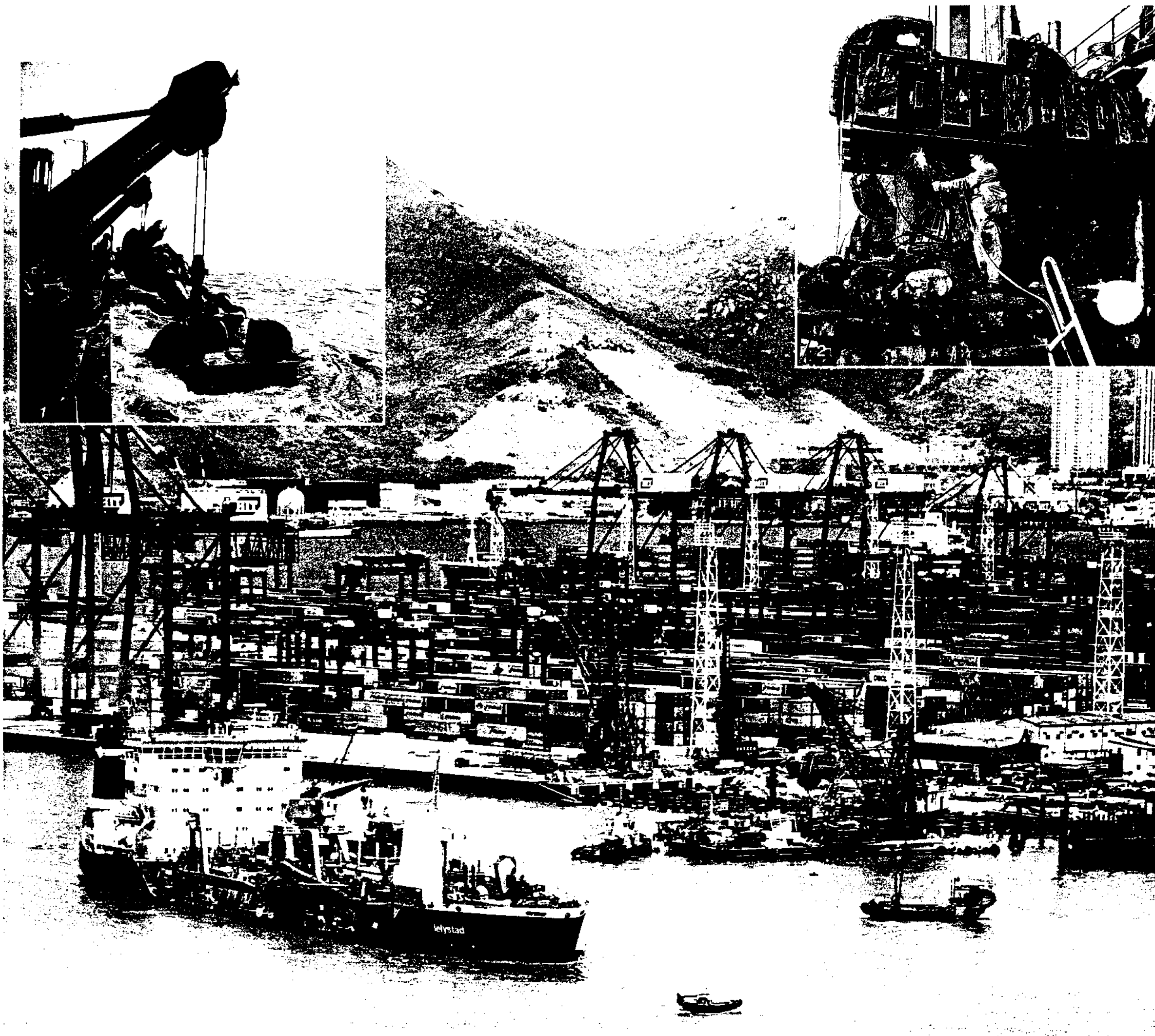

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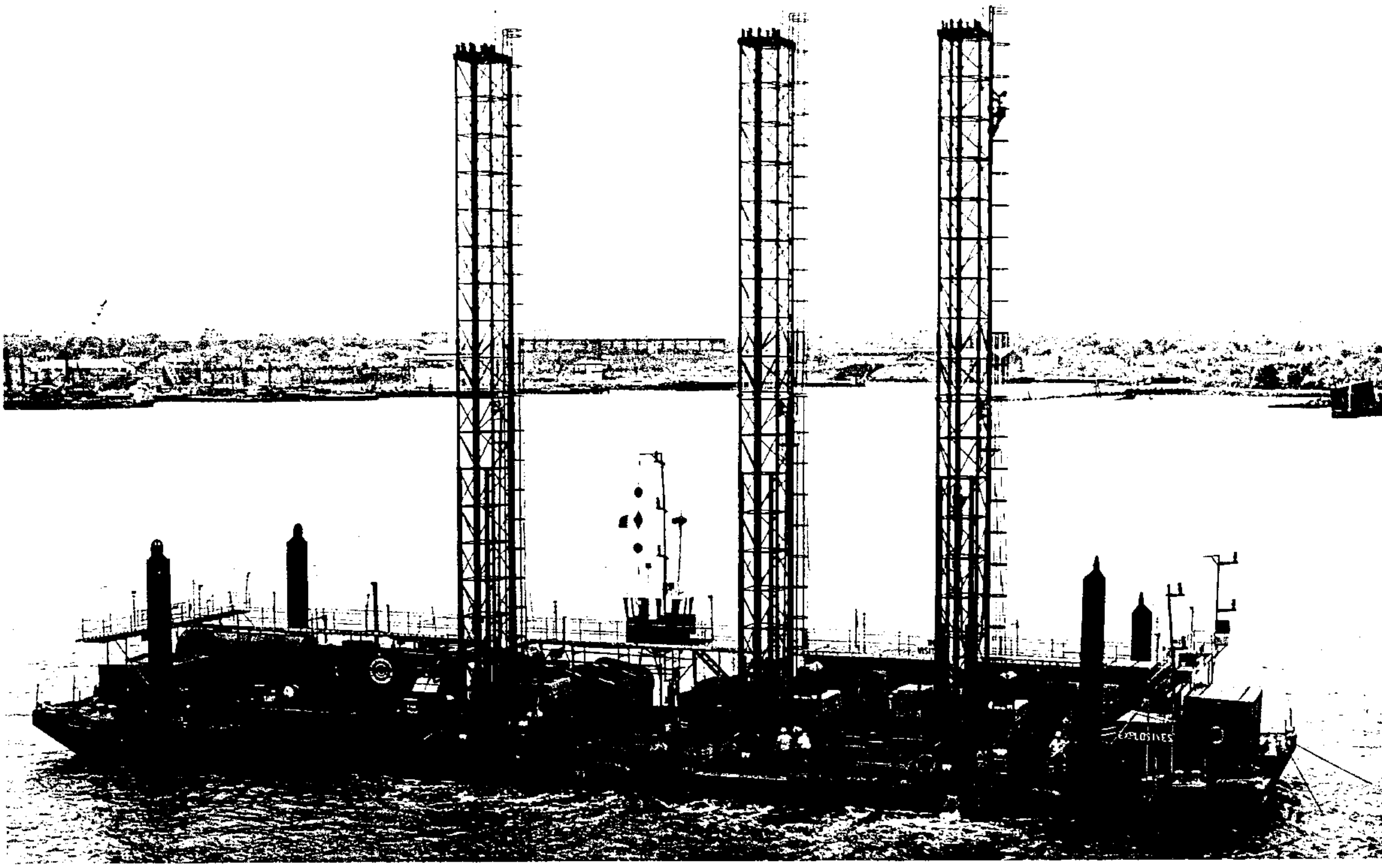
EXHIBIT A-5

DRILL BOATS

Drillboat No. 8 & the *Algonquin*



The **Drillboat No. 8** ***in New York Harbor:*** *GLDD used two drillboats, No. 8 and the Algonquin on the deepening of the Kill Van Kull, the largest dredging project in the history of the U.S. Army Corps of Engineers. The project required drilling and placement of more than 150,000 charges.*

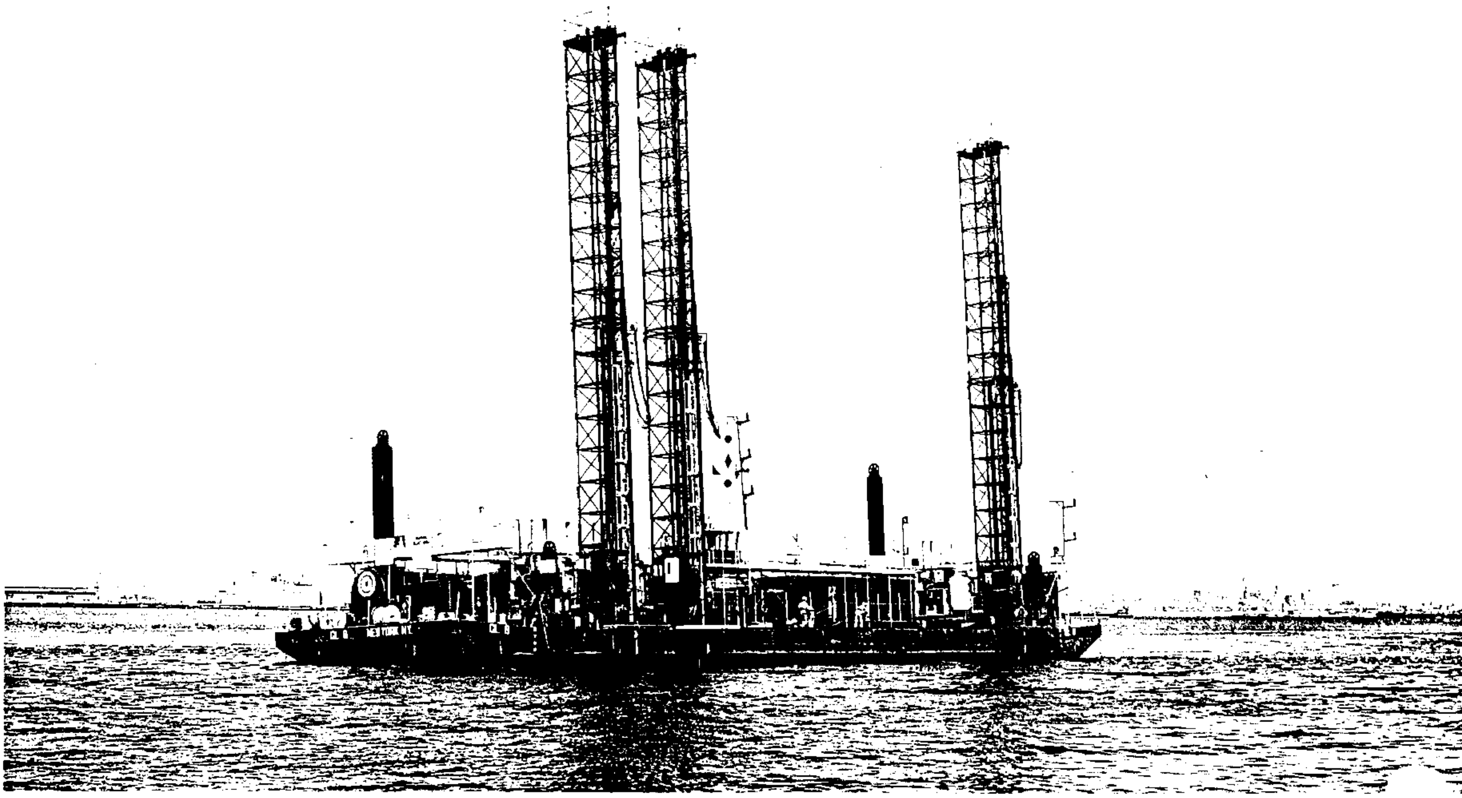
Drillboat No. 8,* the *Algonquin and their predecessors account in large part for Great Lakes' leadership in the field of blasting and removing underwater rock. The company has been involved in most major underwater rock blasting and removal projects in the United States and in many international projects as well, and is a leader in this market.

These drillboats define the state of the art in drillboat technology, including adjustable high-pressure hydraulic percussion drills, adjustable drill towers, and systems to charge and detonate high-safety gel explosives. Solid explosives may also be used with this equipment.

Through the use of advanced explosives technology, each blast is comprised of as many as 44 individual explosions, staggered in micro-second intervals to control shock-wave propagation through adjacent strata and minimize shoreside disturbance.

Drillboat crew members connect detonation lines to rows of drilled holes filled with explosives.

Specifications



Drillboat No. 8 *at work in the Kill Van Kull Channel in New York Harbor.*

Drillboat No. 8

	Imperial	Metric
Dimensions		
Hull	175 x 42 x 8.3 ft	53 x 13 x 2.5 m
Draft	3.6 ft	1.1 m
No. of Drill Frames	3	3
Tower Height	90 ft	27 m
Deck Travel	118 ft	36 m
No. of Spuds	4	4
Spud Length	67 ft	20 m
Performance		
Maximum Hole Depth	75 ft	23 m
Maximum Hole Diameter	5 in	127 mm
Fuel Capacity	10,200 gal	38,600 l

Drillboat Algonquin

	Imperial	Metric
Dimensions		
Hull	135 x 50 x 9.6 ft	41 x 15 x 2.9 m
Draft	6.0 ft	1.8 m
No. of Drill Frames	3	3
Tower Height	90 ft	27 m
Deck Travel	112 ft	34 m
No. of Spuds	3	3
Spud Length	80 ft	24 m
Performance		
Maximum Hole Depth	75 ft	23 m
Maximum Hole Diameter	5 in	127 mm
Fuel Capacity	15,700 gal	59,425 l

Note: Both drillboats use either liquid or solid explosives.

Great Lakes Dredge & Dock Company
2122 York Road Oak Brook, Illinois 60523 U.S.A. 630/574-3000 630/574-2909 *fax*

EXHIBIT A-6

LAND-BASED WET EXCAVATOR

LITRONIC 994 BACKHOE EXCAVATOR

Technical Data:

Weight:	229,000 kg
Installed Power:	840 kW
Bucket Capacity:	4.50 – 20.00 m^3

THE PANAMA CANAL
EVALUATION OF LOCK CHANNEL ALIGNMENTS
PART 4 – REVIEW OF EXCAVATION METHODOLOGIES

APPENDIX B

DRY EXCAVATION EQUIPMENT

THE PANAMA CANAL
EVALUATION OF LOCK CHANNEL ALIGNMENTS
PART 4 – REVIEW OF EXCAVATION METHODOLOGIES

APPENDIX B
DRY EXCAVATION EQUIPMENT

TABLE OF CONTENTS

EXHIBITS

EXHIBIT B-1

POTENTIAL EQUIPMENT LISTS – DRY EXCAVATION

Potential Equipment List - Dry Excavation

OFF ROAD TRUCKS

Model Number	Manufacturer	Capacity tonnes	Capacity tons	Installed Power kW	Installed Power Hp
210 M	Komatsu	54	59.5	478	641
510 E	Komatsu	136	150	955	1280
930 E	Komatsu	290	320	1865	2500
773D	Caterpillar	52.3	57.6	485	650
785C	Caterpillar	136	150	1005	1347
793C	Caterpillar	218	240	1615	2165
797	Caterpillar	326	359	2535	3398

WHEEL LOADERS

Model Number	Manufacturer	Capacity CM	Capacity CY	Installed Power kW	Installed Power Hp
WA800-2	Komatsu	10.5	13.8	588	788
WA900-1	Komatsu	13	17	636	853
988F	Caterpillar	6.9	9	321	430
990II	Caterpillar	9.2	12	466	625
992G	Caterpillar	11.5-12.3	15-16	597	800
994D	Caterpillar	14-31	18-40	933	1251

HYDRAULIC EXCAVATORS

Model Number	Manufacturer	Capacity CM	Capacity CY	Installed Power kW	Installed Power Hp
H135S	Komatsu	10.4	13.6	543	728
H285S	Komatsu	19	24.9	1180	[illegible]82
H665S	Komatsu	35	45.9	2772	[illegible]16
345B L	Caterpillar	N/A	N/A	216	290
375 L	Caterpillar	N/A	N/A	319	428
5130 FS	Caterpillar	11	14.4	641	859
5230 ME	Caterpillar	13-27.5	17-36	1095	1468

AUTORIDAD DEL CANAL DE PANAMA
Oficina de Proyectos de Capacidad del Canal

CONTRACT NO. CC-5-536
EVALUATION OF LOCK CHANNEL ALIGNMENTS
Review of Excavation Methodologies
Potential Equipment List - Dry Excavation

HARZA TAMS | March 2000 | Exhibit B-1

Potential Equipment List - Dry Excavation

EARTH MOVERS

Model Number	Manufacturer	Blade Capacity CM	CY	Installed Power kW	Hp
D375A-3	Komatsu	22	28.8	391	524
D475-A-3	Komatsu	34.4	45.1	641	859
D575A-2 SR	Komatsu	44.3	58	1050	1408
D9R	Caterpillar	N/A	N/A	302	405
D10R	Caterpillar	N/A	N/A	425	570
D11R	Caterpillar	N/A	N/A	634	850

GRADERS

Model Number	Manufacturer	Blade Length M	Ft	Installed Power kW	Hp
GD825A-2	Komatsu	4.9	16.1	209	280
160H	Caterpillar	4.9	16	134	180
16H	Caterpillar	4.9	16	205	275
24H	Caterpillar	7.3	24	373	500

SCRAPERS/ BELT LOADERS

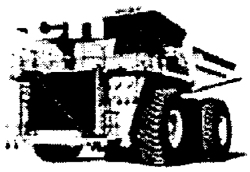
Model Number	Manufacturer	Belt Width M	Ft	Installed Power kW	Hp
610	Holland	2.4	8	522	700
611	Caterpillar	N/A	N/A	198	265
637E	Caterpillar	N/A	N/A	365	489
651E	Caterpillar	N/A	N/A	452	606

EXHIBIT B-2

OFF ROAD TRUCKS

If you plan to PURCHASE **this equipment** OUTSIDE the U.S. *then click here*

If you plan to PURCHASE **this equipment** INSIDE the U.S. *then click here*



Trucks

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210M	Cummins QSK-19	478	641	95	210,000	34	44	54.0	59.5
330M	Komatsu 12V140Z-1	753	1,010	166	367,000	60	79	90.7	100
530M	Cummins KTA50	1,027	1,377	249	550,000	78	102	136	150
510E	Cummins KTTA 38-C	955	1,279	231	510,000	76	100	136	150
630E	Cummins K1800E	1,289	1,728	294	650,000	103	135	172	190
730E	Cummins K2000E	1,388	1,860	324	715,000	111	145	186	205
830E	MTU/DDC 16V4000	1,818	2,409	386	850,650	147	193	231	255
930E	MTU/DDC 16V4000	1,865	2,500	480	1,059,000	184	241	290	320

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KOMATSU
MINING SYSTEMS, INC.

Need something SMALLER? Check out the Komatsu Utility product line at: www.KomatsuUtility.com

KOMATSU DUMP TRUCKS

Model	Flywheel Horsepower	Maximum GVW (lb)	Capacity (ton)	Capacity (cu yd)	Max Travel Speed (mph)
HD325-6	488	159,020	40	31.4	43.5
HD465-5	715	211,860	61	44.7	43.5
HD605-5	715	235,190	61	52.3	43.5
HD785-3	1010	367,000	100	60.0	39.8

These specs are typical for the U.S. market. They may vary in your area. Please consult your local distributor. To find the distributor nearest you, click here.

Materials and specifications are subject to change without notice

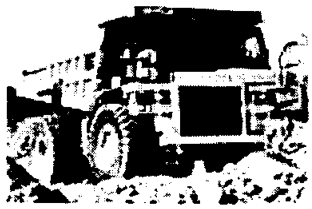
Questions/Comments

Equipment

Off Highway Trucks

Equipment

- Agricultural Tractors
- Articulated Trucks
- Asphalt Compactors
- Asphalt Pavers
- Backhoe Loaders
- Cold Planers
- Combines
- Compactors
- Forest Machines
- Forwarders
- Front Shovels
- Harvesters
- Hydraulic Excavators
- Integrated Toolcarriers
- Knuckleboom Loaders
- Material Handlers
- Motor Graders
- Off Highway Tractors
- Off Highway Trucks
- Pipelayers
- Road Reclaimers
- Scrapers
- Skid Steer Loaders
- Skidders
- Soil Stabilizers
- Telescopic Handlers
- Track Loaders
- Track-Type Tractors
- Wheel Loaders
- Wheel Tractors



Caterpillar builds Off-Highway Trucks specifically for work in mines, construction and quarries. All our Off-Highway Trucks have a mechanical power train. Mechanical-drive trucks lug the engine under load rather than running at constant maximum horsepower. This makes a mechanical power train efficient and productive in a wide variety of conditions. Cat Off-Highway Trucks also are pass-matched with Cat Wheel Loaders to speed cycle times and maximize productivity.

Off Highway

Model	Flywheel Power	Capacity	Top Speed
769D	362 kW / 485 hp	37.9 t / 41.6 Sh Ton	75.2 kph / 46.7 mph
773D	485 kW / 650 hp	52.3 t / 57.5 Sh Ton	65.8 kph / 41.1 mph
777D	699 kW / 938 hp	90.9 t / 100 Sh Ton	60.4 kph / 37.5 mph
785C	1005 kW / 1348 hp	136 t / 150 Sh Ton	54.8 kph / 34 mph
789C	1335 kW / 1791 hp	177 t / 195 Sh Ton	54.4 kph / 33.8 mph
793C	1615 kW / 2166 hp	218 t / 240 Sh Ton	54.3 kph / 33.7 mph
797	2535 kW / 3400 hp		

Quarry

Model	Flywheel Power	Capacity	Top Speed
771D	362 kW / 485 hp	40 t / 44.1 Sh Ton	56.3 kph / 35 mph
775D	517 kW / 693 hp	62.6 t / 69.1 Sh Ton	65.9 kph / 41.1 mph

Dealer Locator

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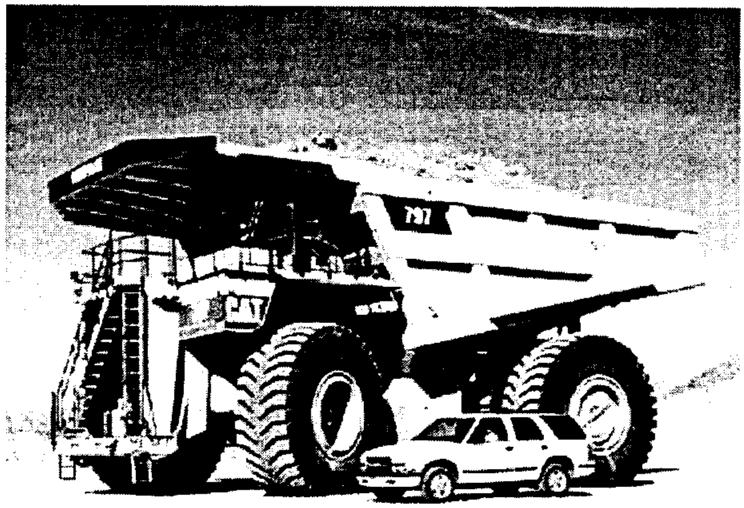
Caterpillar® 797

Back to the Caterpillar 797 Large Mining Truck Press Release



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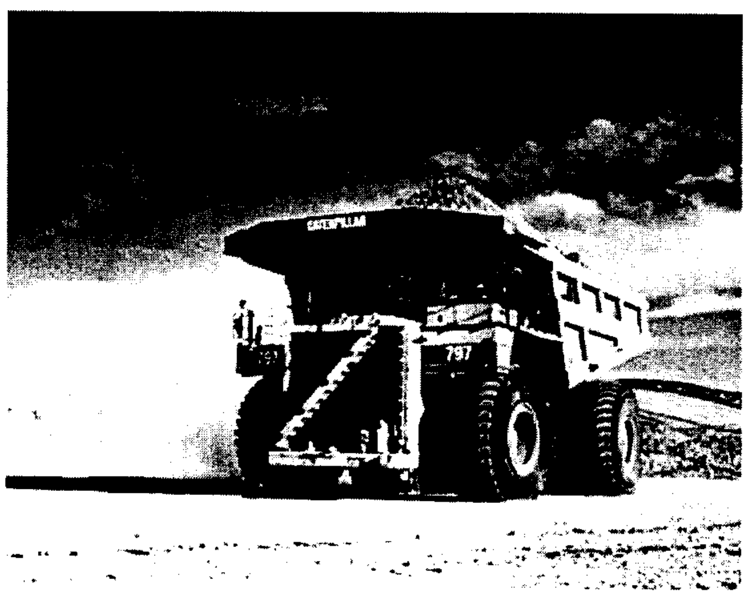

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March 4, 1999

Caterpillar Introduces 797 Mining Truck

The Caterpillar(797 mining truck has a payload capacity of 360 tons (326 metric tons) and design operating weight of 1,230,000 pounds (557 820 kg). The new model is the largest of the extensive Caterpillar off-highway truck line, and it is the largest mining truck ever constructed.

Caterpillar developed the 797 in response to mining companies seeking a means to reduce cost per ton in large-scale operations. The 797 is sized to work efficiently with loading shovels used in large mining operations, and Caterpillar will match the body design to the material being hauled to optimize payloads.

Currently several 797 mining trucks are being tested at Caterpillar proving grounds. Mine evaluations will begin in the second quarter of 1999. The 797 will be available commercially in North America in 2000 and worldwide in 2001.

The Caterpillar(797 was developed using a clean-sheet approach, and it features many patented innovations. But the design also draws on the experience gained from hundreds of thousands of operating hours accumulated by more than 30,000 Caterpillar mining trucks working worldwide. The 797 builds on such field-proven designs as the mechanical power train, electronics that manage and monitor all systems, and structures that provide durability and long life.

Electronically Controlled Engine
The new Cat 3524B High Displacement diesel engine produces 3,400 gross horsepower (2537 kW). It is turbocharged, aftercooled and features Electronic Unit Injection (EUI) technology, which helps the engine meet year 2000 emissions regulations.

The engine uses two in-line blocks linked by an innovative coupler and precisely controlled by electronic controllers. Electronic controllers integrate engine information with mechanical power train information to optimize truck performance, extend component life, and improve operator comfort.

The engine uses a hydraulically driven fan for efficient cooling. The fan design and operation reduce fuel consumption and noise levels. The engine and components are designed to minimize service time, which helps keep availability high.

Efficient Mechanical Power Train
The 797 power train includes a new torque converter with lockup clutch that delivers high mechanical efficiency. The new automatic-shift transmission features seven speeds forward and one speed reverse. Electronic Clutch Pressure

Control (ECPC) technology smoothes shifts, reduces wear and increases reliability. Large clutch discs give the transmission high torque capacity and extend transmission life. The transmission and torque converter enable the truck to maintain good speed up grades and to reach a top speed of 40 miles per hour (64 kilometers per hour).

The modular differential is rear mounted, which improves access for maintenance. The differential is pressure lubricated, which promotes greater efficiency and long life. Each final drive incorporates a nodular iron wheel for high strength and long life. Wide wheel bearing spread reduces bearing loads and helps ensure durability. A hydraulically driven lube and cooling system operates independently of ground speed and pumps a continuous supply of filtered oil to each final drive.

Oil-cooled, multiple disc brakes provide fade-resistant braking and retarding. The electronically managed Automatic Retarder Control (ARC) is an integral part of the intelligent power train. It controls the brakes on grade to maintain optimum engine rpm and oil cooling, and it results in faster downhill speeds. Automatic Electronic Traction Aid (AETA) uses the rear brakes to optimize traction. A combination of constant-displacement and variable-displacement pumps delivers regulated flow of brake cooling oil for constant retarding capability and peak truck performance on downhill grades.

Cast Frame
Mild steel castings comprise the entire load-bearing frame for durability and resistance to impact loads. The nine major castings are machined for precise fit before being joined using a robotic welding technology that ensures full penetration welds. The frame design reduces the number of weld joints and ensures a durable foundation for the 797.

The suspension system uses oil-over-nitrogen struts similar to other Caterpillar mining trucks. It is designed to dissipate haul road and loading impacts.

Electrohydraulic Hoist Control
New hoist hydraulics include an electronic hoist control, Independent Metering Valve (IMV) and a large hoist pump. The features allow automatic body snubbing for reduced impact on the frame, hoist cylinders and operator. The design also allows the operator to modulate flow and control over-centering when dumping.

Comfortable and Efficient Operator Station
The 797 cab is designed to reduce operator fatigue, enhance operator performance, and promote safe operation. The controls and layout provide greater operator comfort and an automotive feel while enhancing functionality and durability. The cab and frame design meets SAE standards for rollover and falling object protection.

- The truck and cab design provides exceptional all-around visibility. The clean deck to the right of the cab improves sight lines.
- The spacious cab includes two full-sized air suspension seats, which allow a trainer to work with the operator.
- The steering column tilts and telescopes so the operator can adjust it for comfort and best control.
- The Vital Information Management System (VIMS) display and keypad provide precise machine status information.
- The new hoist control is fingertip actuated and allows

the operator to more easily and precisely control hoist functions-raise, hold, float and lower.

- Electrically operated windows and standard air conditioning add to operator comfort.
- The cab is resiliently mounted to dampen noise and vibration, and sound-absorbing material in the doors and side panels cuts noise further.
- Built-in storage compartments and a cup holder accommodate the operator's needs, and a high-capacity power inverter satisfies auxiliary power requirements.

Serviceability
Caterpillar designed the 797 to reduce service time for maximum availability. Routine maintenance points, such as fluid fill and check points, are close to ground level. Easily accessed connectors allow technicians to download data and to calibrate machine functions, and extended maintenance intervals further increase availability.

The 797 is designed to make major components accessible. Accessibility effectively reduces removal, installation and in-truck maintenance time for all drive train components.

To allow technicians to raise the truck body inside a standard height maintenance building, the canopy portion of the body is hinged so that it can be folded back. In the folded and raised position, the 797 body height is no higher than the 793, the Caterpillar 240-ton (218-metric ton) capacity mining truck.

Caterpillar 797 Mining Truck Specifications	
Engine Model	3524B High Displacement
Gross Power at 1750 rpm	3,400 hp (2537 kW)
Net Power at 1750 rpm	3,224 hp (2404 kW)
Transmission	7-Speed Planetary Power Shift
Top Speed	40 mph (64 km/hr)
Operating Weight	1,230,000 lb. (557 820 kg)
Nominal Payload Capacity	360 tons (326 metric tons)
Body Capacity (SAE 2:1)	290 cubic yards (220 cubic meters)
Tire Size	55/80R63

Images
Click to see photographs of the 797 Large Mining Truck

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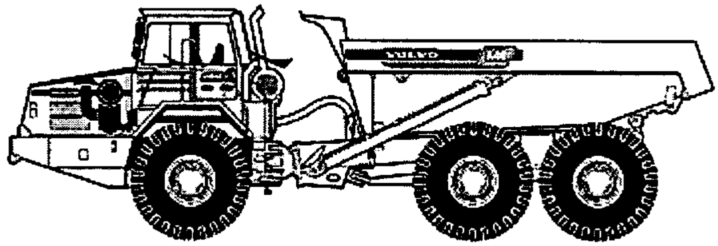
Volvo A40 6x6



Engine		Volvo TD 122 KFE	
Rated output, at	r/s (rpm)	35	(2 100)
SAE J1349 gross	kW (hp)	297	(398)
SAE J1349 net	kW (hp)	295	(395)
Max. torque, at	r/s (r/min)	23	(1 380)
SAE J1349 gross	Nm	1 675	
SAE J1349 net	Nm	1 665	
Max. speed	km/h	53	
Load capacity			
SAE struck	m^3	16,3	
SAE 2:1 heap	m^3	22,0	
Payload	t	36,0	
Net weight	t	30,1	
Gross weight	t	66,1	

All products are not sold on all markets
Contact your local dealer for more information

EXHIBIT B-3

WHEEL LOADERS

If you plan to **PURCHASE this equipment OUTSIDE the U.S.** *then click here*

If you plan to **PURCHASE this equipment INSIDE the U.S.** *then click here*

Loaders

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WA800-2	69,000	152,145	10.5	13.7	4640	15'3"	588	789	92,589	204,124
WA900-1	62,100	136,910	13.0	17.0	4640	15'3"	636	828	94,720	208,340

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KOMATSU
MINING SYSTEMS, INC.

Questions/Comments

The New Volvo L220D

Volvo has once again put its innovation skills to work and come up with a solution that lowers fuel consumption while increasing overall performance.

We've given that solution a name: Volvo L220D.

The L220D is a new 349 hp, 4,5-14 m3 bucket, 30-tonne Volvo wheel loader featuring a full shopping list of smart Volvo innovations. These are some of the most important features:

Load-sensing hydraulics
Unique in a 30-tonne loader, the load-sensing hydraulic system means you use just the right amount of oil at the right time.

High Performance Low Emission Engine
Volvo TD122KLE engine with twin pump intercooling means high torque from low r/min as well as low emissions.

Oil cooling-heating system
The engine, transmission, axles and hydraulic system are equipped with an ingenious integrated cooling/heating system.

Care Cab II
Superb operator comfort, safety, allround visibility and fingertip control.

Load-sensing steering
Low fuel consumption and easy steering at low r/min are just two benefits of the load-sensing steering system.

Contronic II
Volvo's world beating machine watchdog keeps the operator informed and gives the service technician a complete overview of its operating history.

TP Linkage
Unique patented linkage system combining parallel lift action with high breakout torque throughout the whole lifting cycle .

APS II and pulse width modulation
A choice of four gear shifting programs and the market's first, and now even better, automatic powershift.

Boom Suspension System

Screen saver

Down load a screen saver
Windows 95/NT (2.50 Mb)
Windows 3.11 (2.68 Mb)

View pictures

L220D (31 kb)

L220D (26 kb)

L220D (34 kb)

Technical info

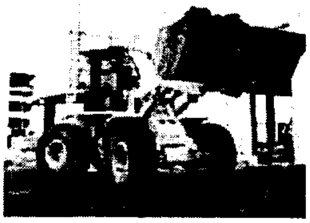
L220D

Equipment

Wheel Loaders

Equipment

- Agricultural Tractors
- Articulated Trucks
- Asphalt Compactors
- Asphalt Pavers
- Backhoe Loaders
- Cold Planers
- Combines
- Compactors
- Forest Machines
- Forwarders
- Front Shovels
- Harvesters
- Hydraulic Excavators
- Integrated Toolcarriers
- Knuckleboom Loaders
- Material Handlers
- Motor Graders
- Off Highway Tractors
- Off Highway Trucks
- Pipelayers
- Road Reclaimers
- Scrapers
- Skid Steer Loaders
- Skidders
- Soil Stabilizers
- Telescopic Handlers
- Track Loaders
- Track-Type Tractors
- Wheel Loaders
- Wheel Tractors



Caterpillar builds a complete line of wheel loaders, including the world's largest, the Cat 994D. The Cat 914G was the first in our new line of G-Series wheel loaders. These new models are more versatile, perform better and more efficiently, are easier to service and are more comfortable. Our medium-sized wheel loader line now includes the 938G, 950G, 962G, 966G, 972G and 980G. These models are designed to perform equally well in bank and face excavation and in second gear truck loading. The latest addition to the wheel loader line is the range of Caterpillar Compact Wheel Loaders. The 902 and 906 Compact Wheel Loaders are now available. This line of Compact Wheel Loaders draws on Caterpillar's extensive wheel loader experience to set new standards of excellence. Since Caterpillar serves customers with different requirements in all regions of the world, we build several different configurations of wheel loaders. Your Cat dealer can help you choose the wheel loader that best matches your application.

Compact

Model	Net power @ 2600 rpm	Gross Power @ 2600 rpm	ISO 9249 Rating
902	34 kW / 45 hp	36 kW / 48 hp	34 kW / 45 hp
906	45 kW / 60 hp	47 kW / 63 hp	45 kW / 60 hp

Small

Model	Model	Power - Gross	Power - Net
914G	Cat 3054T	73 kW / 98 hp	67 kW / 90 hp
924F	Cat 3114T	83 kW / 111 hp	78 kW / 105 hp
928G	Cat 3116T	102 kW / 137 hp	93 kW / 125 hp

Medium

Model	Flywheel Power	Operating Weight	Bucket Range
938G	108 kW / 145 hp	13030 kg / 28731 lb	2.1-3.3 m3 (2.75-3.65 yd3)
950G	134 kW / 180 hp	17428 kg / 38411 lb	2.5-3.3 m3 (3.25-4.25 yd 3)
962G	149 kW / 200 hp	18295 kg / 40322 lb	2.9-3.8 m3 (3.75-5.0 yd3)
966G	175 kW / 235 hp	22865 kg / 50410 lb	3.3-4.0 m3 (4.25-5.25 yd3)
972G	198 kW / 265 hp	25085 kg / 55310 lb	3.8-4.7 m3 (5.0-6.0 yd3)
980G	224 kW / 300 hp	29519 kg / 65078 lb	3.8-5.7 m3 (5.0-7.5 yd3)

Large

Equipment

Wheel Loaders

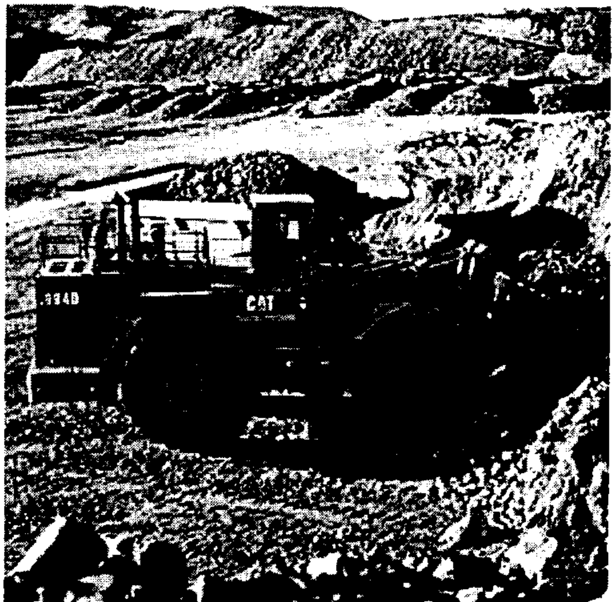
› 994D

OTHER MODELS 994D

› SPECIFICATIONS FEATURES & BENEFITS: -- Select --

Product Overview

The 994D builds on its productive tradition with innovations that enhance performance, reliability, durability and operator comfort, helping lower cost-per-ton.



Related Industries: Heavy Construction, Mining

↑ BACK TO TOP

Equipment

Wheel Loaders

› 994D

OTHER MODELS 994D

› SPECIFICATIONS FEATURES & BENEFITS: -- Select --

Detailed Specifications

Engine	
Flywheel Power	933 kW (1250 hp)
Power at TC Stall/Hyd at Relief	933 kW (1250 hp)
Weights	
Operating Weight	191200 kg (421600 lb)
Operating Specifications	
Bucket Range	14.0-31.0 m3 (18.0-40.0 yd3)

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EXHIBIT B-4

HYDRAULIC EXCAVATORS

Equipment

Hydraulic Excavators

› 5230 ME

Other Models 5230 ME

› SPECIFICATIONS

Product Overview

The 5230 Mass Excavator is a high production loading tool for use in mining and large project excavation work. Its sophisticated electronics, stress resistance modular components and powerful hydraulic systems makes it a very quick, responsive excavating tool.

Related Industries: Mining

BACK TO TOP

Equipment

Hydraulic Excavators

› 5230 ME

OTHER MODELS 5230 ME

› SPECIFICATIONS

Detailed Specifications

Engine	
Flywheel Power	1095 kW (1470 hp)
Weights	
Operating Weight	316600 kg (698000 lb)
Operating Specifications	
Bucket Capacity Range	13-27.5 m3 (17-36 yd3)

BACK TO TOP

If you plan to **PURCHASE this equipment OUTSIDE the U.S.** *then click here*

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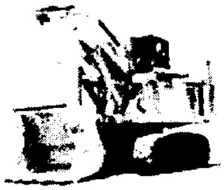

Shovels

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H135S	Cummins VTA 28-C	543	728	N/A	140	308,600	10.4	13.6	11.5	38
H255S	Cummins K1500E	900	1,207	900	240	530,000	14.0	18.3	13.5	44
H285S	Cummins K2000E	1,180	1,580	1,190	335	738,500	19.0	25.0	14.5	48
H455S	2 X Cummins KTTA 38-C	1,670	2,236	1,700	490	1,080,500	25.0	33.0	16.5	55
H655S	2X3516 DI-TA	2,772	3,714	2X 1350	685	1,510,000	35.0	46.0	17.5	58

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MINING SYSTEMS, INC.

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Questions/Comments

Model	Flywheel Power	Operating Weight	Maximum Reach
320B L	96 kW / 128 hp	20620 kg / 45400 lb	10.7 m / 35.1 ft
322B L	114 kW / 153 hp	23860 kg / 52600 lb	10.6 m / 34.75 ft
325B L	125 kW / 168 hp	27530 kg / 60600 lb	10.5 m / 34.6 ft
330B L	165 kW / 222 hp	34660 kg / 76300 lb	11.7 m / 38.25 ft
345B L	216 kW / 290 hp	44050 kg / 97100 lb	13 m / 42.7 ft

Large

Model	Flywheel Power	Operating Weight	Maximum Reach
365B L	279 kW / 374 hp	64600 kg / 142420 lb	14 m / 46.08 ft
375	319 kW / 428 hp	81190 kg / 178800 lb	15.9 m / 52.3 ft
375 L	319 kW / 428 hp	82380 kg / 181500 lb	15.9 m / 52.3 ft
375 L ME	319 kW / 428 hp	81900 kg / 180400 lb	13.08 m / 42.9 ft

Mass Excavation

Model	Flywheel Power	Operating Weight	Bucket Capacity Range
5230			
5230 ME	1095 kW / 1470 hp	316600 kg / 698000 lb	13-27.5 m3 (17-36 yd3)

Wheeled

Model	Flywheel Power	Operating Weight	Maximum Reach
M318	98 kW / 131 hp	18000 kg / 39558 lb	8.7 m / 28.5 ft
M320	105 kW / 140 hp	20640 kg / 45400 lb	

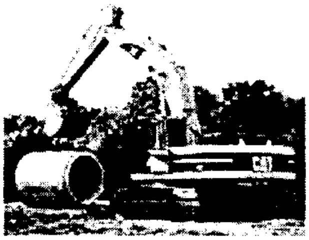
Dealer Locator

Equipment

Hydraulic Excavators

Equipment

- Agricultural Tractors
- Articulated Trucks
- Asphalt Compactors
- Asphalt Pavers
- Backhoe Loaders
- Cold Planers
- Combines
- Compactors
- Forest Machines
- Forwarders
- Front Shovels
- Harvesters
- Hydraulic Excavators
- Integrated Toolcarriers
- Knuckleboom Loaders
- Material Handlers
- Motor Graders
- Off Highway Tractors
- Off Highway Trucks
- Pipelayers
- Road Reclaimers
- Scrapers
- Skid Steer Loaders
- Skidders
- Soil Stabilizers
- Telescopic Handlers
- Track Loaders
- Track-Type Tractors
- Wheel Loaders
- Wheel Tractors



The Caterpillar 300 Family Excavators are recognized by their sleek, modern styling and feature innovative hydraulic systems that put power where and when it's needed most. The 300 Family gives you the choice of the boom, stick, bucket and undercarriage that best meets your job requirements. Our new line of wheeled excavators incorporates design features in styling, operator comfort and ease of maintenance to make them highly efficient. Your Cat dealer can help you choose tires, outriggers, dozer blades, buckets and other attachments that best meet your job requirements. Since Caterpillar serves customers with different requirements in all regions of the world, we build several different configurations of hydraulic excavators. Certain models are available only in specific areas. Your Cat dealer has the exact machine specifications available in your area and can help you choose the machine configuration that best meets your needs.

Mini Hydraulic

Model	Net power	Operating weight with cab	Max digging depth - standard stick
301.5	13 kW / 17.4 hp	1673 kg / 3687 lb	2130 mm / 7 ft
302.5	17.1 kW / 22.9 hp	2734 kg / 6015 lb	2650 mm / 8.66 ft

Small

Model	Power - Net	Operating Weight	Max Reach at Ground Level
307B	40 kW / 54 hp	7818 kg / 17235 lb	6736 mm / 22.1 ft
307B SB	40 kW / 54 hp	6759 kg / 14900 lb	7420 mm / 24.3 ft
311B	59 kW / 79 hp	11419 kg / 25175 lb	8100 mm / 26.58 ft
312B	63 kW / 84 hp	12735 kg / 28080 lb	8625 mm / 28.3 ft
312BL	63 kW / 84 hp	13009 kg / 28680 lb	8625 mm / 28.3 ft
315B	74 kW / 99 hp	16094 kg / 35480 lb	9140 mm / 30 ft
315BL	74 kW / 99 hp	16511 kg / 36410 lb	9140 mm / 30 ft
318B	86 kW / 115 hp	18390 kg / 40540 lb	8790 mm / 28.83 ft

Medium

Model	Flywheel Power	Operating Weight	Bucket Range
988F Series II	321 kW / 430 hp	45678 kg / 100697 lb	6.1-6.9 m3 (8.0-9.0 yd3)
990 Series II	466 kW / 625 hp	73453 kg / 161597 lb	8.4-9.2 m3 (11.0-12.0 yd3)
992G	597 kW / 800 hp	93848 kg / 206897 lb	11.5-12.3 m3 (15.0-16.0 yd3)
994D	933 kW / 1250 hp	191200 kg / 421600 lb	14.0-31.0 m3 (18.0-40.0 yd3)

Waste Handling Arrangement

Model	Flywheel Power	Operating Weight	Bucket Range
938G WHA	108 kW / 145 hp	13605 kg / 30000 lb	2.7-4.2 m3 (3.5-5.5 yd3)
950G WHA	127 kW / 170 hp	18027 kg / 39750 lb	2.7-2.9 m3 (3.5-3.8 yd3)
966G WHA	175 kW / 235 hp	22865 kg / 50410 lb	3.3-4.0 m3 (4.25-5.25 yd3)
980G WHA	224 kW / 300 hp	29519 kg / 65078 lb	3.8-5.7 m3 (5.0-7.5 yd3)

Dealer Locator

Equipment
Front Shovels

› 5130B FS

5130B FS

› SPECIFICATIONS FEATURES & BENEFITS: -- Select --

Detailed Specifications

Engine	
Flywheel Power	597 kW (800 hp)
Engine Model	Cat 3508B EUI
Gross Power	641 kW (860 hp)
Weights	
Operating Weight	181000 kg (399000 lb)
Operating Specifications	
Max Bucket Capacity	11 m^3 (14.5 yd^3)
Travel Speed	3.3 kph (2.1 mph)
Drawbar Pull	872 kN (196000 lb)
Max Reach	12.4 m (40.7 ft)
Max Reach at Ground Level	8.3 m (27.2 ft)
Max Level Crowd Distance	4.3 m (14.1 ft)
Max Loading Height	9.1 m (29.8 ft)
Crowd Force	770 kN (173000 lb)
Breakout Force	715 kN (161000 lb)
Fuel Tank	
Fuel Tank Capacity	2600 L (687 Gal)

↑ BACK TO TOP

EXHIBIT B-5

EARTH MOVERS/ TRACTORS

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D375A-3	391	525	68	149,180	18.5-22.0	24.2-28.8	1.45	20.7
D475A-3	641	860	95	228,530	25.6-34.4	33.5-45	1.67	22.9
D475A-3 SD	641	860	104	230,380	45.0	58.9	1.48	21.0
D575A-2 SD	858	1,150	143	314,200	69.0	90.0	1.51	21.5
D575A-2 SR	784	1,050	132	290,980	44.3	58.0	1.92	27.3

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KOMATSU
MINING SYSTEMS, INC.

Questions/Comments

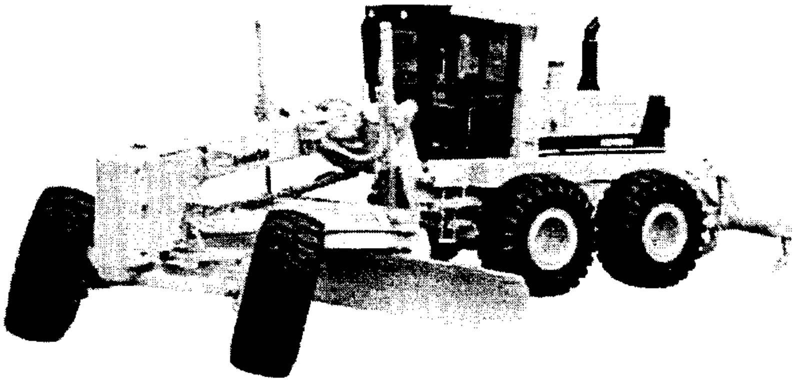
EXHIBIT B-6

GRADERS

KOMATSU

GD825A-2 Motor Grader

- Full Specs ▶
- Standard Equipment ▶
- Optional Equipment ▶
- Need a Quote? Let us Know! ▶
- Ready to Buy? Contact us! ▶



Specifications

Engine

Standard make and model		Komatsu S6D140E
Fuel		Diesel
Number of cylinders		6
Operating cycle		4 stroke
Flywheel power* @ 2100 rpm	280 HP	209 kW
*Flywheel power:	*Flywheel power is the rated power at the engine flywheel minus the average accessory losses. Accessories include fan and charging alternator. Rating(s) represent gross engine performance in accordance with SAE J1349 conditions.	

Transmission

The Komatsu HYDROSHIFT Transmission utilizes planetary gears and hydraulically actuated, force-lubricated multiple-disc clutches. A single lever completes both speed shifting and direction changes. Inching pedal allows precise finishing operation and smooth machine starts. Eight forward and reverse speeds match all job requirements. Gearshift lock device prevents accidental machine starts. Engine starts only when the shift lever is set in the park position.

Travel speeds (at rated engine rpm):

1st Gear Forward	2.5 mph	4.0 km/h
1st Gear Reverse	2.7 mph	4.3 km/h
2nd Gear Forward	3.4 mph	5.4 km/h
2nd Gear Reverse	3.6 mph	5.8 km/h
3rd Gear Forward	5.0 mph	8.0 km/h
3rd Gear Reverse	5.3 mph	8.5 km/h
4th Gear Forward	7.1 mph	11.5 km/h

4th Gear Reverse	7.6 mph	12.2 km/h
5th Gear Forward	9.8 mph	15.8 km/h
5th Gear Reverse	10.5 mph	16.9 km/h
6th Gear Forward	13.3 mph	21.4 km/h
6th Gear Reverse	14.2 mph	22.8 km/h
7th Gear Forward	19.5 mph	31.3 km/h
7th Gear Reverse	20.8 mph	33.4 km/h
8th Gear Forward	27.9 mph	44.9 km/h
8th Gear Reverse	29.8 mph	47.9 km/h
Maximum drawbar pull	31,790 lb	14 420 kg

Electrical System

12-volt batteries	Two 12-volt batteries in series/parallel. 200 ampere-hour capacity with disconnect switch.	
Alternator		24-volt, 50 amp
Starter	24-volt	11 kW

Final Drive

Double-reduction final drives consisting of a spiral bevel gear with electric-over, hydraulically controlled differential lock/unlock device and planetary gear. Roller-chain tandem drives for four rear wheels. Tandem case pivots up to 15°, assuring high machine stability and positive traction during operation.

Axles

Front:		
Elliot-type front		
Center ground clearance	2'3"	680 mm
Oscillation angle		32° (total)
Front wheel lean (to each side)		14.5°
Rear:		
Full-floating rear axle is made of forged heat-treated steel.		

Tires/Rims

Front and rear tires		23.5 x 25-12PR (L3) tires
Rims		13.00 VA x 25 TB
Inflation pressure	37 psi	2.6 kg/cm²

Steering

Full-hydraulic orbit-roll-type steering control system with two steering cylinders directly actuated on the knuckle arm.

Steering angle (max.)		50° (front wheels, left and right)
Frame articulation angle		25° (left and right)
Turning radius (min.)	25'11"	7.9 m (frame articulated)

Braking System

Service brakes:

Rear	Air-actuated, wet, multiple-disc brakes on four rear wheels. Sealed for adjustment-free operation. Two, crossed brake lines.
Parking brake	Mechanical, dry, disc-type, mounted on transmission output shaft. Spring-applied and air-released.

Frames

Box-sectioned front and rear frames are welded steel plate construction and connected with an articulation pin. One-piece frame design for the front frame in which hydraulic piping is installed offers excellent front visibility for precise operations. Frames are articulated by two hydraulic cylinders.

Front (WxH)	1'2" x 1'4"	350 mm x 400 mm

Blade Range

All blade movements and positions can be hydraulically controlled from the operator's seat.

Lift (max. above ground)	1'7"	490 mm
Drop (max. below ground)	2'3"	680 mm
Shoulder reach (max.): Left	7'10"	2400 mm
Shoulder reach (max.): Right	7'10"	2400 mm
Bank cutting angle (max.)		90°
Hydraulic blade tip: Forward		49°
Hydraulic blade tip: Backward		5°
Cutting angle		25.5 - 84°

Blade Equipment

Drawbar	A-shaped, U-section press-formed and welded construction for maximum strength.

Circle	Hydraulically controlled, internal gear-type circle with six guide shoes for smooth 360 degrees rotation.	
Circle diameter (outer)	5'10"	1775 mm
Moldboard	Box-section construction with wear-resistant steel. Hydraulic brake sideshift and tip control. Reversible overlay end bits and side edges are attached.	
Length x height x thickness	16'2" x 2'7" x 0.98"	4928 mm x 800 mm x 25 mm
Blade base	10'2"	3100 mm
Blade load	30,250 lb	13720 kg
Cutting edges	Curved-type cutting edges meet SAE J739b.	
Noumber of cutting edges		2
Length x height x thickness	8' x 10" x 1"	2438 mm x 254 mm x 25 mm

Operating Weight (approximate)

Includes rated capacity of lubricant, coolant, full fuel tank, hydraulic equipment, operator, 16'2" 4928 mm blade and 23.5 x 25-12PR (I3) rock-type tires, optional ROPS canopy with steel cab (low-profile) and standard equipment.

On front axle	17,570 lb	7970 kg
On rear axle	40,680 lb	18450 kg
Total weight	58,250 lb	26420 kg

Hydraulic System

Control valves: Two, 5-spool-type control valves for sure control.

Hydraulic cylinders: Double-acting piston-type hydraulic cylinders, two for blade lifting, one for drawbar sideshifting, one for blade sideshifting, one for front wheel leaning, one for blade tipping, two for front wheel steering, and two for frame articulation. Pilot check valves ensure positive cylinder action (excluding a blade sideshift cylinder).

Pumps:		
Steering/work equipment (piston-type)	73.4 U.S. gal	278 ltr
Transmission (gear-type)	35.1 U.S gal	133 ltr
Differential (gear-type)	4.5 U.S. gal	17 ltr
Motor:		
Piston-type (for blade rotation)	66 HP	49 kW
Relief valve setting:		
Work equipment	3,560 psi	250 kg/cm²
Steering	2,490 psi	175 kg/cm²
Transmission	440 psi	31 kg/cm²

Service Capacities

Coolant	15.3 U.S. gal	58 ltr
Fuel tank	132.1 U.S. gal	500 ltr
Engine	10 U.S. gal	38 ltr
Transmission	6.6 U.S. gal	25 ltr
Tandem case (each side)	50.2 U.S. gal	190 ltr
Final drive case	16.6 U.S. gal	63 ltr
Hydraulic oil	21.1 U.S. gal	80 ltr

Ripper

Rear-mounted riper: Four, parallel-linkage-type. With hydraulically controlled raise and lower functions, this ripper can be used to dig out rocks or hard ground not removable by a scarifier.

Number of shanks (maximum 7 shanks installable)		3
Digging depth (maximum)	1'7"	480 mm
Lift above ground (maximum)	2'3"	675 mm
Digging width (maximum)	9'9"	2980 mm
Additional weight (including front push-plate)	5,700 lb	2585 kg

ROPS

ROPS canopy and steel cab* includes cigarette lighter and ashtray, dome light, sun visor, front window washer and front and rear wipers, seat belt, right and left outside and interior rearview mirrors.

Low-profile:		
Weight	2,205 lb	1000 kg
Installed height	11'8"	3550 mm
Weight	2,470 lb	1120 kg
Full-height:		
Installed height	12'4"	3750 mm

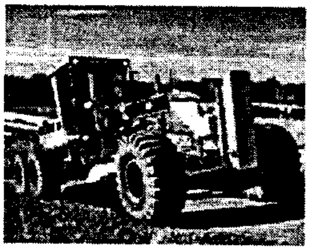
*ROPS canopy or ROPS cab must be ordered for all machines.

Language
English

Equipment

- Agricultural Tractors
- Articulated Trucks
- Backhoe Loaders
- Cold Planers
- Combines
- Compactors
- Forest Machines
- Forwarders
- Front Shovels
- Harvesters
- Hydraulic Excavators
- Integrated Toolcarriers
- Knuckleboom Loaders
- Material Handlers
- Motor Graders
- Off Highway Tractors
- Off Highway Trucks
- Paving Equipment
- Pipelayers
- Road Reclaimers
- Scrapers
- Skid Steer Loaders
- Skidders
- Soil Stabilizers
- Telehandlers
- Track Loaders
- Track-Type Tractors
- Wheel Loaders
- Wheel Tractors

Equipment
Motor Graders



From finish or long pass grading to ditch cleaning or sideslope work, you are certain to find a Cat motor grader to match your needs. Caterpillar unveiled the H-Series motor graders in 1994. They replace our legendary G-Series motor graders introduced 22 years earlier. In our new H-Series motor graders, you advised us to keep those things that made the G-Series successful: durability, performance, high resale and reliability. We did that while adding H-Series improvements including more power to the ground, better visibility, a more comfortable and quiet cab, lower emissions, and better control. With advanced electronics and hydraulics combined with variable horsepower options, longer wheel bases and a new blade design, our H-Series motor graders allow you to handle in one pass what may take two or more passes with a G-Series model.

Motor Grader

Model	Flywheel Power - Net	Flywheel Power - Variable	Operating Weight
12H	104 kW / 140 hp		14247 kg / 31410 lb
14H	160 kW / 215 hp		18784 kg / 41410 lb
120H	93 kW / 125 hp	104 kW / 140 hp	12519 kg / 27600 lb
135H	101 kW / 135 hp	116 kW / 155 hp	12950 kg / 28550 lb
140H	123 kW / 165 hp	138 kW / 185 hp	14724 kg / 32460 lb
160H	134 kW / 180 hp	149 kW / 200 hp	15586 kg / 34360 lb

All Wheel Drive

Model	Flywheel Power - Net	Flywheel Power - Variable	Operating Weight
143H	123 kW / 165 hp	138 kW / 185 hp	15023 kg / 33120 lb
163H	134 kW / 180 hp	149 kW / 200 hp	16538 kg / 36460 lb

Mining

Model	Flywheel Power - Net	Flywheel Power - Variable	Operating Weight
16H	205 kW / 275 hp		24748 kg / 54560 lb
24H	373 kW / 500 hp		61955 kg / 136611 lb

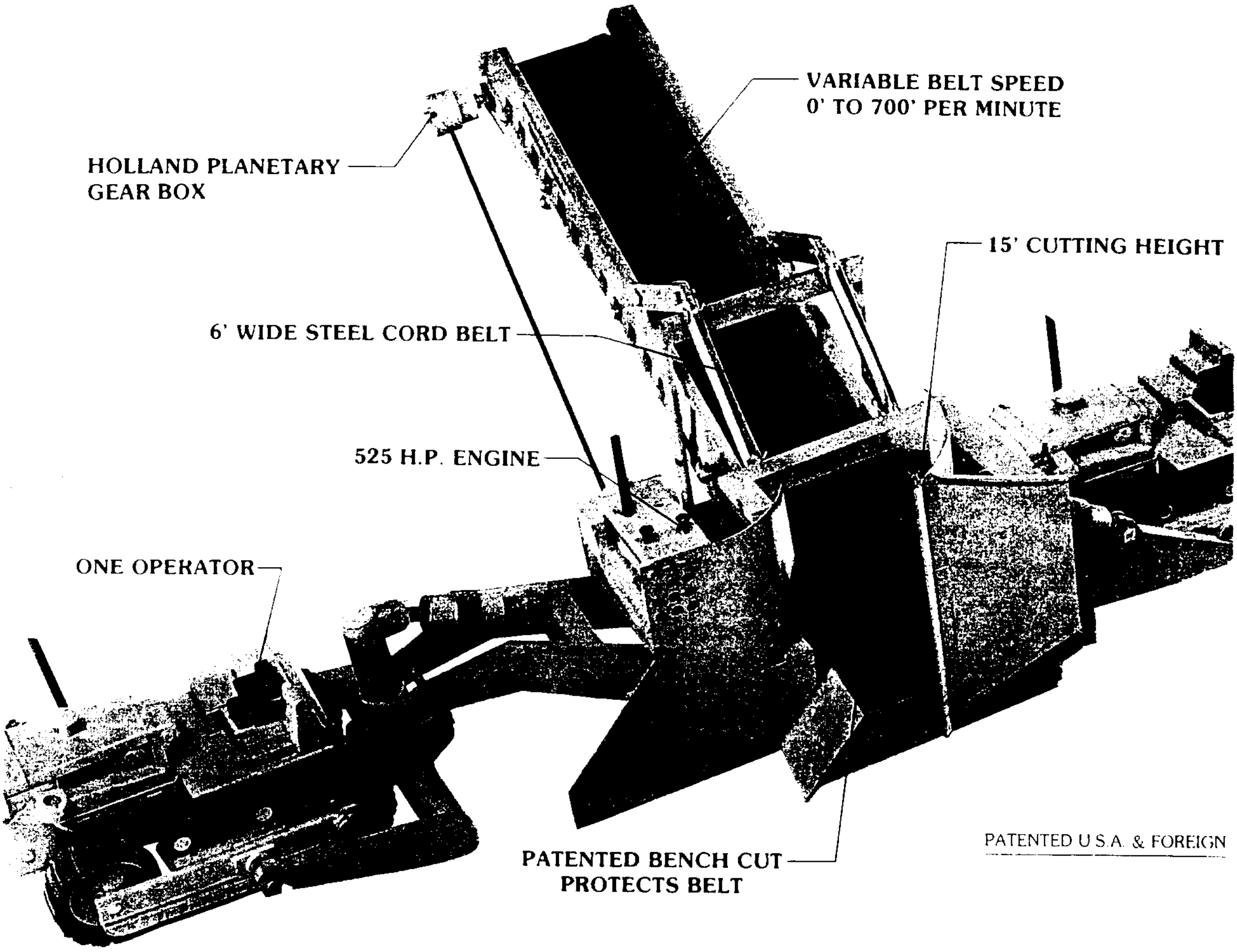
Dealer Locator

EXHIBIT B-7

SCRAPERS/ BELT LOADERS

HOLLAND

EXCAVATOR/LOADERS



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SERIES HI MODEL 600

VERTICAL CUTTING EXCAVATOR/LOADER

The Key to Reduced Costs . . .

. . . Excavate & Load Fast

Francis H Holland
President and Chief Executive Officer

WHY THE HOLLAND LOADER

I have often been asked why I developed the Holland Loader To answer the question I have to go back to my freshman and sophomore years in high school My older brother and I constructed a dam, ¾ mile of canal and some dikes on the home ranch just north of Billings, Montana Our equipment was 4 horses and a Fresno During and after that job I was determined to find a better way

In the early 1940's the self-propelled scraper was being developed, crawler tractors were getting better and a few old conveyor belt muckers and bottom dumps were around. At that time it was my opinion that the Euclid BV Belt Loader and bottom dumps were far superior to any other equipment available

In 1948 I started contracting in a small way I did not have cost accounting but I always figured the bottom dump being so simple, durable and light should move material cheaper than scrapers. Fast loading was the key and the old Euclid BV Loader was the best to be had

The company grew and in 1957 we incorporated and set up our costing system. In 1959-60 we moved 10,000,000 yards with scrapers, bottom dumps and 15 year old Euclid BV Loaders. New 24 yard struck scrapers cost twice as much to operate as 24 yard struck Euclid bottom dumps with 50,000 hours use.

From 1961 through 1969 we had many jobs -- dams and state and interstate highways. Under various job conditions, using an assortment of scrapers and bottom dumps, we continued to prove that belt loaded bottom dumps will move material for 50% of what it costs for push-loaded scrapers and that scraper costs can be greatly reduced by top loading with a traveling belt loader. It was obvious that a dependable high capacity belt loader would further reduce costs but I couldn't buy one.

So, in 1969 I organized the Holland Loader Co. and started manufacturing our high capacity, rugged, dependable excavator loader.

We are proud of the fact that our Loaders and traveling conveyors are now working on major projects throughout the free world

Francis H Holland

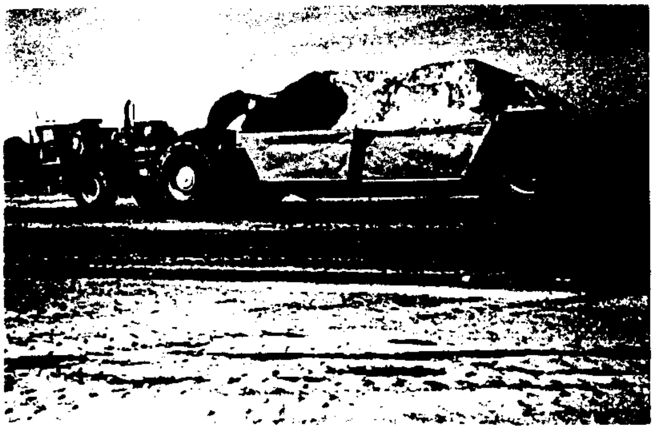
Francis H. Holland.
President

TEL: 406-656-2506
FAX: 406-652-6254

HOLLAND LOADER CO.
HOLLAND CONSTRUCTION CO.

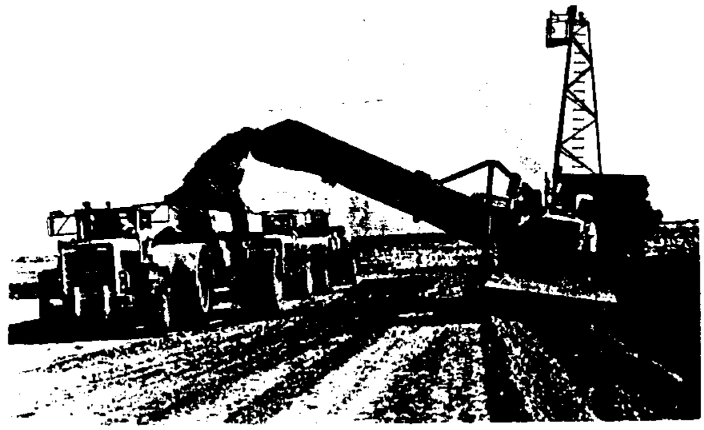
2450 SOUTH 32ND ST. WEST, BILLINGS MT 59102

Equipment Manufacturers
Designers & Fabricators

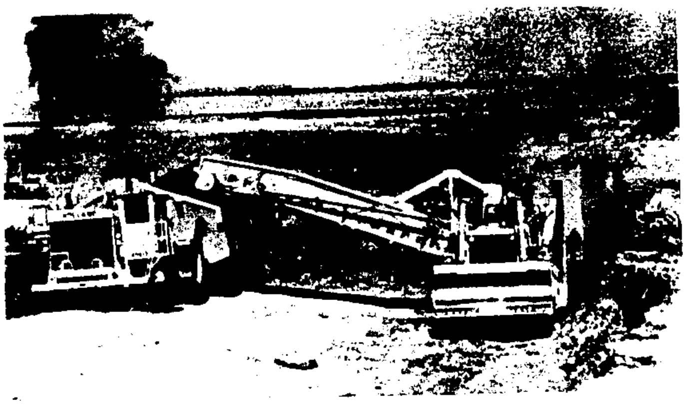


116 BANK CU YD CAPACITY MOBILIZATION

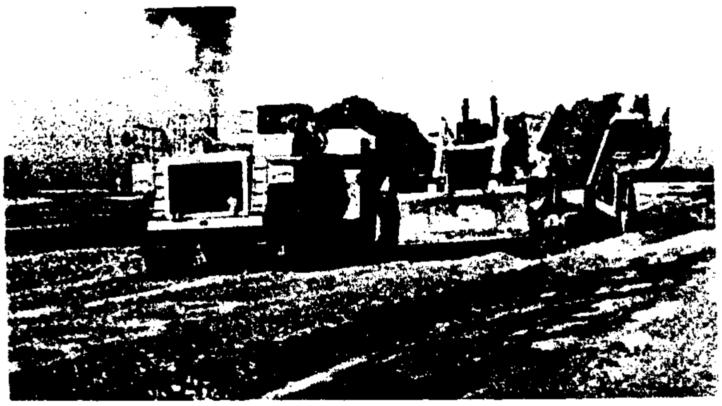
2 MEN 8 HOURS. 4 LOADS LEGAL HEIGHT, LENGTH, WEIGHT, AND UNDER 12' WIDE.



MODEL 600 LOADER AT 2ND OR 3RD PASS STARTING A NEW CUT. LOADING 145 TONS OF DECOMPOSED GRANITE IN 43 - 47 SECONDS. THE DECOMPOSED GRANITE HAD TO BE RIPPED FOR THE PRECEDING EUCLID LOADERS & SCRAPERS.



610 LOADER ON 700 H.P. D10's
3,000 to 10,000 Y.P.H. 8'BELT



MODEL 700 LOADER IN HARD PAN. 8' WIDE BELT
240 TON TRAILER 30 - 40 SECONDS

700 LOADERS CHARGING MODEL 80 CONVEYORS

LEFT SEPARATED
5000 - 6000 Y.P.H

8' WIDE BELT

RIGHT ATTACHED CROSSING HIGHWAY ON 5 MILE RUN

TEL: 406-656-2506
FAX: 406-652-6254

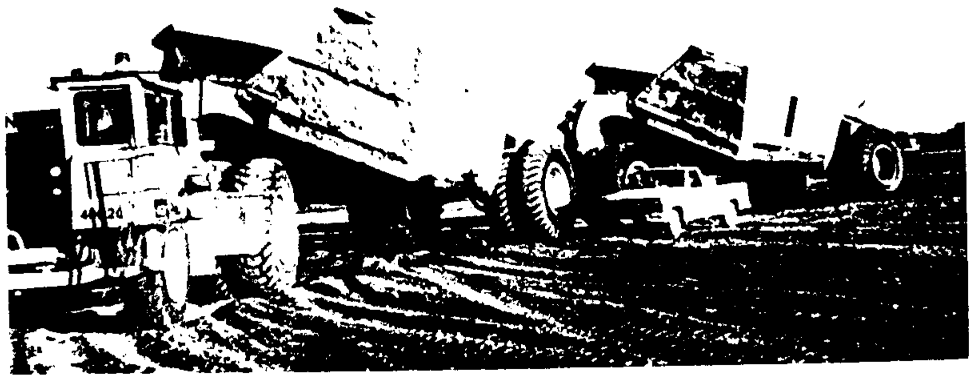
HOLLAND LOADER CO.

HOLLAND CONSTRUCTION CO.

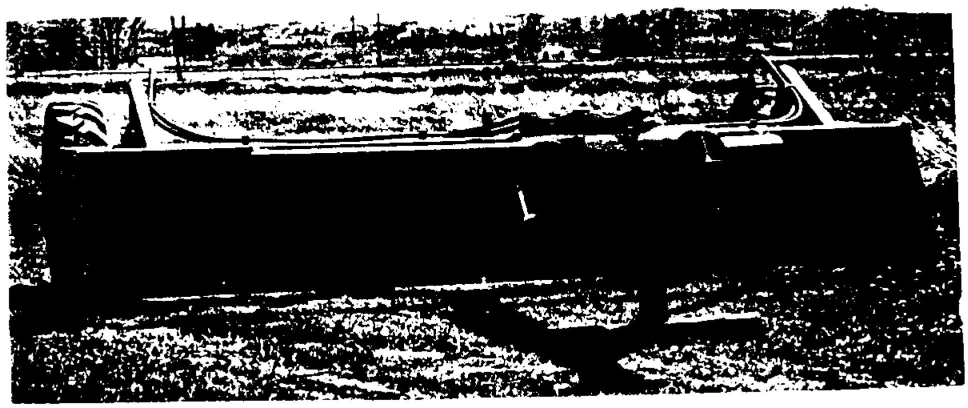
2450 SOUTH 32ND ST. WEST, BILLINGS MT 59102

Equipment Manufacturers
Designers & Fabricators

THE BEST MOBILITY IN SOFT GROUND OF ANY HAUL UNIT ON THE MARKET.



1 TRUCK - 2 TRAILERS 232 B.C.Y.



A ROAD LEVELER CAN DO AS MUCH AS 3 MODEL 16 CAT PATROLS

DOZER TRAP

THE 2-ENGINE 4-WHEEL DR. 1200 HP HOLLAND BOTTOM DUMP WITH 2700 x 49 TIRES HAS BEEN USED TO PULL 988 F.E. LOADERS, D10's & SINGLE AXLE HAUL UNITS FROM MUD HOLES

OTHER PRODUCTS MANUFACTURED BY HOLLAND ARE: BRIDGE CRANES TO 100' & 40 TON
OUTSIDE CRANES TO 206' & 90 TON WATER TANKS TO 20,000 GALLONS
CONVEYOR BELTS UP TO 8' WIDE 2" THICK --- STEEL CHORD, VARIOUS LENGTHS ENDLESS.
LOADERS & HAUL UNITS ARE THE MOST FUEL EFFICIENT, DURABLE, COST EFFICIENT ON EARTH BY A LARGE MARGIN - ABOUT 25% of the COMPETITION

We designed the trailer front end wider and higher putting more weight on the drive axle which out performs the old bottom dump designed and built in the past.

Equipment
Scrapers

Caterpillar wheel tractor-scrapers have the power, traction, and speed for continuous high output in a wide range of materials, conditions, and applications. Scraper options include single engine open bowls, tandem engine open bowls, tandem engine push-pulls, elevators, and auger arrangements. Tandem engine push-pulls, elevators, and augers have self-loading capability which eliminates the need for a push-cat. The auger configuration is available in the 621, 627, 631, 637, 651, and 657 open bowl scrapers. Caterpillar scrapers load quickly, have high travel speeds, and compact as they dump and spread on the run. Less support equipment is needed which lowers the overall owning and operating cost due to scrapers' ability to work independently. Your Caterpillar dealer can help you decide which scraper best meets your hauling unit needs.

Single Engine Open Bowl

Model	Flywheel Power Gears 1-2	Flywheel Power Gears 3-8	Capacity Heaped
611	197.5 kW / 265 hp		11 m^3 / 15 yd^3
621F	246 kW / 330 hp		15.3 m^3 / 20 yd^3
631E Series II	335 kW / 450 hp	365 kW / 490 hp	23.7 m^3 / 31 yd^3
651E	410 kW / 550 hp	452 kW / 605 hp	33.6 m^3 / 44 yd^3

Tandem Engine Open Bowl

Model	Flywheel Power-Tractor	Flywheel Power-Scraper	Capacity-Heaped
627F	246 kW / 330 hp	168 kW / 225 hp	15.3 m^3 / 20 yd^3
637E Series II	365 kW / 490 hp	186 kW / 250 hp	23.7 m^3 / 31 yd^3
657E	451 kW / 605 hp	328 kW / 440 hp	33.6 m^3 / 44 yd^3

Elevating

Model	Flywheel Power	Operating Weight	Capacity Heaped
613C Series II	131 kW / 175 hp	15264 kg / 33650 lb	8.4 m^3 / 11 yd^3
615C Series II	197.5 kW / 265 hp	25605 kg / 56450 lb	13 m^3 / 17 yd^3
623F	272 kW / 365 hp	36886 kg / 81250 lb	17.6 m^3 / 23 yd^3
633E Series II	366 kW / 490 hp	51065 kg / 112580 lb	26 m^3 / 34 yd^3

Coal Bowl

Model	Flywheel Power Tractor	Flywheel Power Scraper	Capacity Heaped
637E Series II Coal	365 kW / 490 hp	186 kW / 250 hp	38.3 m^3 / 50 yd^3
657E Coal	451 kW / 605 hp	328 kW / 440 hp	55.5 m^3 / 72.6 yd^3

Dealer Locator

Equipment

Scrapers

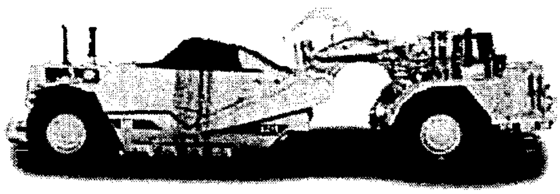
>637E Series II

OTHER MODELS: 637E Series II

> SPECIFICATIONS FEATURES & BENEFITS: -- Select--

Product Overview

The Cat 637E Series II Scraper's rugged construction and easy maintenance assure long life with low operating costs. The scraper bowl design combined with hydraulic ejection provides fast cycle times for high productivity.



Related Industries: Heavy Construction

Engine	
Flywheel Power-Tractor	365 kW (490 hp)
Flywheel Power-Scraper	186 kW (250 hp)
Net Power Tractor Gears 1-2	335 kW (450 hp)
Net Power Tractor Gears 3-8	365 kW (490 hp)
Net Power Scraper Gears 1-2	-
Operating Specifications	
Capacity-Heaped	23.7 m^3 (31 yd^3)

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Equipment

Scrapers

› 637E Series II   OTHER MODELS 637E Series II

› SPECIFICATIONS   FEATURES & BENEFITS: -- Select--

Detailed Specifications

Engine	
Flywheel Power-Tractor	365 kW (490 hp)
Flywheel Power-Scraper	186 kW (250 hp)
Net Power Tractor Gears 1-2	335 kW (450 hp)
Net Power Tractor Gears 3-8	365 kW (490 hp)
Net Power Scraper Gears 1-2	-
Engine Model Tractor	3408E
Engine Model Scraper	3306
Gross Power Tractor Gears 1-2	354 kW (475 hp)
Gross Power Tractor Gears 3-8	384 kW (515 hp)
Gross Power Scraper Gears 1-2	-
Gross Power Scraper Gears 3-8	-
Net Power Scraper Gears 3-8	-
Operating Specifications	
Capacity-Heaped	23.7 m^3 (31 yd^3)
Capacity Rated Load	34020 kg (75000 lb)
Travel Speed Maximum	54.9 kph (34.1 mph)
Capacity Struck	16.1 m^3 (21 yd^3)
Weights	
Operating Weight Total	50990 kg (112320 lb)
Operating Weight Tractor	30084 kg (66269 lb)
Operating Weight Scraper	20906 kg (46051 lb)
Fuel Tank	
Fuel Tank Capacity Scraper	1268 L (337 Gal)

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Equipment

Scrapers

› 651E   OTHER MODELS 651E

› SPECIFICATIONS FEATURES & BENEFITS -- Select--

Product Overview

Cat scraper bowl design combined with hydraulic ejection provides fast cycle times for high productivity.

Engine	
Flywheel Power Gears 1-2	410 kW (550 hp)
Flywheel Power Gears 3-8	452 kW (605 hp)
Net Power	-
Operating Specifications	
Capacity Heaped	33.6 m^3 (44 yd^3)
Capacity Rated Load	47175 kg (104000 lb)
Weights	
Operating Weight	61127 kg (134760 lb)

↑ BACK TO TOP

Equipment

Scrapers

› 651E OTHER MODELS 651E

› SPECIFICATIONS FEATURES & BENEFITS: -- Select--

Detailed Specifications

Engine	
Flywheel Power Gears 1-2	410 kW (550 hp)
Flywheel Power Gears 3-8	452 kW (605 hp)
Net Power	-
Engine Model	3412E
Gross Power	-
Gross Power Gears 1-2	430 kW (577 hp)
Gross Power Gears 3-8	472 kW (632 hp)
Operating Specifications	
Capacity Heaped	33.6 m^3 (44 yd^3)
Capacity Rated Load	47175 kg (104000 lb)
Travel Speed Maximum	53 kph (33 mph)
Capacity Struck	24.5 m^3 (32 yd^3)
Weights	
Operating Weight	61127 kg (134760 lb)
Operating Weight Tractor	40344 kg (88942 lb)
Operating Weight Scraper	20783 kg (45818 lb)
Fuel Tank	
Fuel Tank Capacity Scraper	954 L (252 Gal)

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THE PANAMA CANAL
EVALUATION OF LOCK CHANNEL ALIGNMENTS
PART 4 – REVIEW OF EXCAVATION METHODOLOGIES

APPENDIX C

GLOBAL POSITIONING SYSTEM EQUIPMENT

THE PANAMA CANAL
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APPENDIX C
GLOBAL POSITIONING SYSYEM EQUIPMENT

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EXHIBITS

EXHIBIT C-1

REAL TIME KINEMATIC RECEIVER

MS750

Dual Frequency RTK Receiver for Precise Dynamic Positioning

Key features and benefits

- **20 Hz position update rate**
- **Less than 20 milliseconds position latency**
- **Centimeter-level position accuracy**
- **Front panel display & keypad for status monitoring and configuration**
- **User-defined local coordinates direct from receiver**
- **Industry standard CAN bus interface**

The MS750 represents the highest level of accuracy and response available from a dual frequency GPS receiver. The receiver is specifically designed to allow the easy integration of reliable centimeter-level positions to any guidance or control application.

Dual Frequency RTK Receiver for Precise Dynamic Positioning

Accuracy and Response Times

Dynamic platforms, require virtually instantaneous position reports multiple times per second. The MS750 delivers positions to guidance or control loop software twenty times per second with a latency of less than 20 milliseconds. This responsiveness is matched with a horizontal accuracy of two centimeters and vertical accuracy of three centimeters. For the most precise applications, the MS750 provides one centimeter accuracy horizontally at a 5 Hz rate with a small increase in latency.

Interfacing and Configuration Ease

The MS750 is designed to plug right into your application with minimal development. An easy-to-use application file interface enables the user to completely program receiver operation with a single command. Alternately, the receiver can be configured via the user-friendly built-in display and keyboard interface, or by the included Windows-based Configuration Toolbox software. Multiple configurations can be stored in the receiver as files and activated when desired. Local datum and transformation parameters may be loaded directly into the receiver. Therefore, output grid coordinates are compatible with GPS and traditional survey systems that may be in use on the same site. ASCII or Binary messages may be output through any of the three bi-directional serial ports. The receiver also includes support for the industry standard CAN (Controller Area Network) interface.

Advanced Technology

The accuracies, update rates and latencies available in the MS750 are made possible through a GPS architecture specifically designed for demanding dynamic positioning applications. Reliable operation in the most adverse environments, such as radio interference experienced at construction or mining sites, is a strict requirement. Custom designed hardware with Supertrak™ multibit GPS signal technology and Everest™ advanced multipath suppression provide superior tracking especially for weaker, low elevation satellites.

Both the RTCM format for differential GPS corrections and Trimble's published Compact Measurement Record (CMR) differential data can be received simultaneously, allowing the receiver to choose the optimum source and provide seamless navigation. Available as an option is the ability to calculate the baseline vector between two moving receivers to centimeter accuracy. The MS750 addresses a vast range of applications in the field of machine positioning, guidance and control.

MS750

Dual Frequency RTK Receiver for Precise Dynamic Positioning

STANDARD FEATURES

- Centimeter accuracy, real-time positioning
- 20 Hz position updates
- < 20 ms position latency
- Front panel display & keypad
- User-defined local coordinates direct from receiver
- 3 serial I/O ports
- 2 CAN ports
- 1 PPS Output
- Trimble CMR Input/Output
- RTCM Input/Output
- One year hardware warranty
- Compact, easy mounting design
- Synchronized 5 Hz position updates

OPTIONS AND ACCESSORIES

- Moving Base RTK
- Rugged L1/L2 machine mount antenna
- Micro-Centered Antenna
- 5 m, 7.5 m, 10 m, 24 m & 30 m antenna cables
- Data extension cable
- Extended hardware warranty
- Firmware and Software update service

ORDERING INFORMATION

MS750 **Part Number 36577-00**

Includes MS750 receiver, Configuration Toolbox software, operating manual, power/data cable, data/1 PPS cable

PHYSICAL CHARACTERISTICS

Size	14.5 cm W × 5.1 cm H × 23.9 cm D (5.7″ W × 2.0″ H × 9.4″ D)
Weight	1.0 kg (2.25 lbs)
Power	12 VDC/24 VDC, 9 Watts

ENVIRONMENTAL CHARACTERISTICS

Operating temp	–20°C to +60°C
Storage temp	–30°C to +80°C
Humidity	MIL 810 E, Meth. 507.3 Proc III, Aggravated, 100% condensing
Vibration	MIL 810 D, Tailored Random 3 gRMS Operating Random 6.2 gRMS Survival
Mechanical Shock	MIL 810 D ± 40 g Operating ± 75 g Survival
EMC	
Radiated Emissions	CISPR 12
Conducted Emissions	SAE J1113/41
Radiated Immunity	ISO/DIS 13766, 30 V/m
ESD	±15 KV
Input Voltage Transients	ISO 7637-2

TECHNICAL SPECIFICATIONS

Tracking	9 channels L1 C/A code, L1/L2 full cycle carrier Fully operational during P-code encryption
Signal processing	Supertrak Multibit Technology Everest Multipath Suppression

Positioning mode	**Accuracy**[1]	**Latency**[2]	**Max Rate**
Synchronized RTK	1 cm + 2 ppm Horizontal 2 cm + 2 ppm Vertical	300 ms[3]	5 Hz Std
Low Latency	2 cm + 2 ppm Horizontal[4] 3 cm + 2 ppm Vertical	< 20 ms	20 Hz
DGPS	< 1 m	< 20 ms	20 Hz

[1] sigma level
[2] At maximum output rate
[3] Dependent on data link throughput
[4] Assumes 1 second data link delay

Initialization	Automatic OTF (on-the-fly) while moving
Time required	Typically < 1 minute
Range	Up to 10 km from base for RTK
Start-up	< 90 seconds from power on to positioning < 30 seconds with recent ephemeris
Communications	3 × RS-232 ports. Baud rates up to 115,200 2 × CAN/J1939
Configuration	Via front panel display & keypad, Configuration Toolbox Software or user definable application files
Output Formats	NMEA-0183: GGK, GGA, ZDA, VTG, GST, PJT and PJK Trimble Binary Streamed Output

Trimble
ADDING VALUE TO GPS

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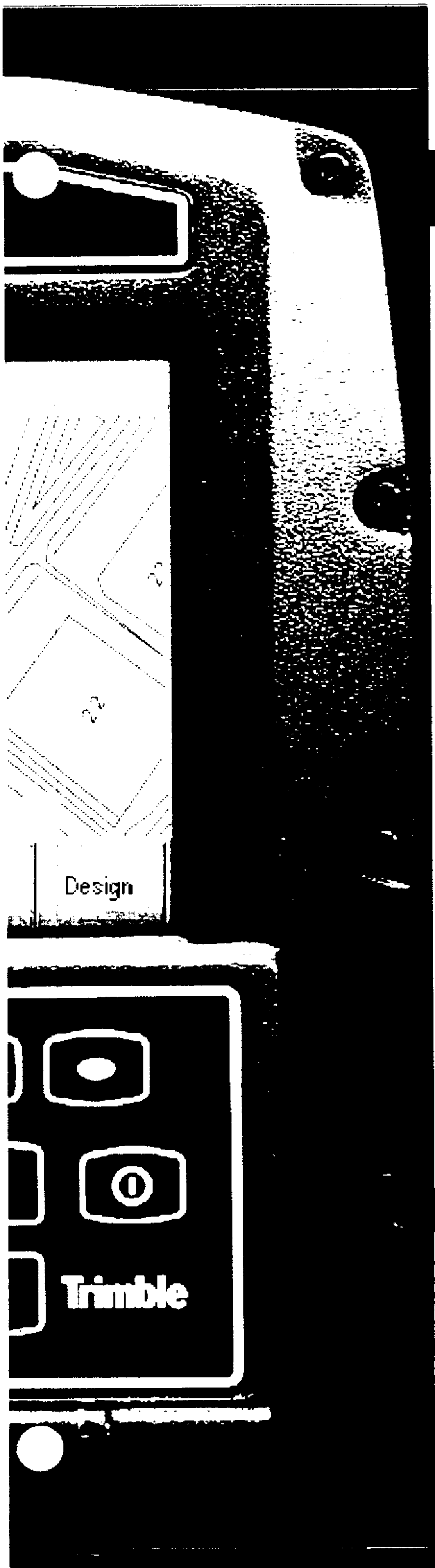
EXHIBIT C-2

SITE VISION GPS



SiteVision GPS

SiteVision GPS™ by Trimble is an earthmoving grade control system that allows operators to "see" design surfaces, grades and alignments from inside the cab. Machine position versus site plan is displayed on a rugged color monitor, providing quick location of embankments and pad corners. Light bars mounted in the operator's field of view guide operators to cut or fill along alignments. Road alignments and cul-de-sacs are located and defined with minimal assistance from grade setters or stakes.

By placing the site plan in the cab, **SiteVision GPS** enables operators to bring the site up to consistent and accurate grade that makes finishing faster, more efficient and more predictable.

SiteVision GPS is based on the same technology developed by Trimble that is revolutionizing earthmoving in demanding mining environments. Trimble now brings its renowned experience in developing GPS-based civil engineering tools and machine guidance systems to the construction earthworks contractor. **SiteVision GPS** is a simple, easy to use, rugged machine accessory, giving you more value and greater return from your machine and your operator.

stakeless

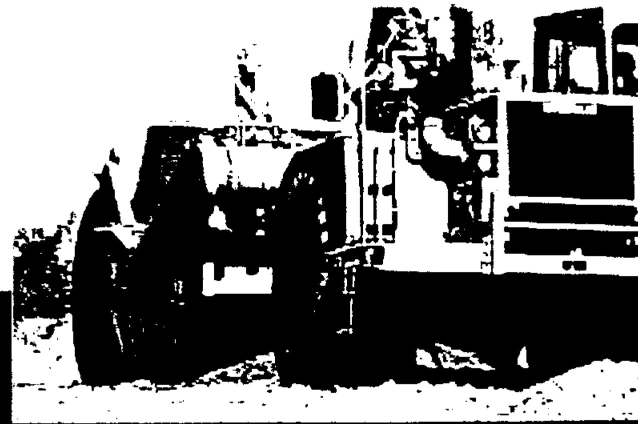
grade control

SiteVision GPS

Grade Control System

Trimble
ADDING VALUE TO GPS

applications



SITE PREPARATION

◎ BALANCING ◎ CONTOURING ◎

◎ TOPSOIL STRIPPING ◎ RESIDENTIAL DEVELOPMENT ◎

ROAD & HIGHWAY CONSTRUCTION

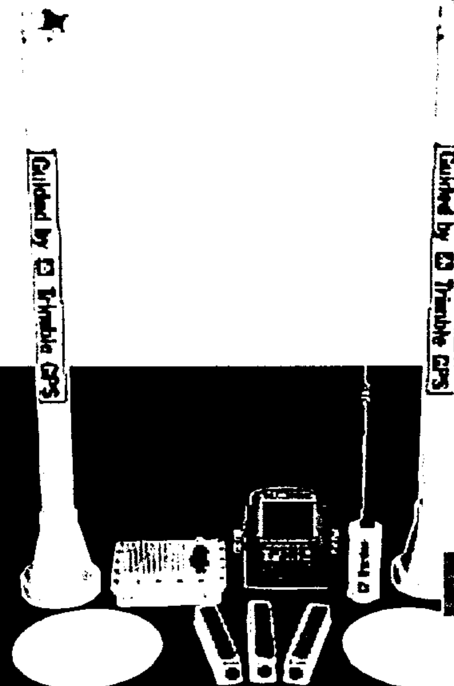
◎ MASS EARTHWORKS ◎ SUB-BASE PLACEMENT AND LEVELING ◎

◎ DRAINAGE AND STORM WATER RETENTION BASINS ◎ SUPER-ELEVATED CURVES ◎

SiteVision GPS

features

- Daylight readable, color display
- Multiple views of the design information, including: Plan View Map, Sectional View, Text View (Cut/Fill, Offset, Stationing)
- Proven ruggedized components designed specifically for construction earth-moving, including GPS receivers, antennas, lightbars, color display and radios
- Easy-view, "on-grade" light bars provide blade position guidance
- Supports numerous design packages such as Infrasoft Ltd. MX products, Intergraph InRoads and InRail, AutoDesk Civil Design, and many other 3rd party formats
- Easy to install and move between machines



benefits

- **IN-CAB GRADE CONTROL**
  SiteVision GPS displays the site plan right in the cab, enabling operators to accurately determine position and control grade. Surveying and grade checking costs are dramatically reduced.
- **FASTER JOB CYCLES**
  Placing grade information in the cab empowers operators to make fast decisions with minimal supervision. Operators know where grade is as well as the locations of design elements. The result is that with **SiteVision GPS**, more earth is moved per day, and jobs finish faster.
- **FASTER RESPONSE TO CHANGES**
  Need to make an in-field change? With SiteVision GPS, the foreman or operator can quickly select the new grade or pad elevation right in the cab, without waiting for grade stakes to be set or repositioned.
- **REDUCED FUEL AND MAINTENANCE COSTS**
  Accurately controlling grade from within the cab means grade is achieved in fewer passes, with less rework. The result is better machine utilization and fewer hours per volume of earth moved, equating to lower fuel and maintenance costs.
- **FLEXIBILITY**
  Meet tight schedules regardless of wind, dust, fog, or darkness, without restrictions on visibility or site conditions. **SiteVision GPS** can be installed on multiple machines and each system is modular for easy transfer to other equipment.

easy to use. really!

Machine operators find **SiteVision GPS** very easy to learn and use, because it is simple and intuitive. At the beginning of the shift, the foreman puts the day's design on a data card, and inserts it into the front of the display unit. In operation, the display shows a map with the machine position on it, while the lightbars indicate how much the left and right corners of the cutting edge need to be moved relative to the design alignment. With a single key press, the operator can switch between the plan view map and the blade orientation display. The blade orientation display shows a picture of the blade position relative to the design surface.

For road construction, **SiteVision GPS** provides left-right offset guidance from a designated alignment. The operator can select which part of the blade to guide along the alignment. One press of a button changes the unit from plan view to blade display, which indicates the blade position relative to the design grade.

What is GPS and How Is It Used?

The Global Positioning System (GPS) was designed, by the U.S. Department of Defense (DOD). In 1996, a Presidential Directive was issued that committed the U.S. government to provide the signal free to civilian users.

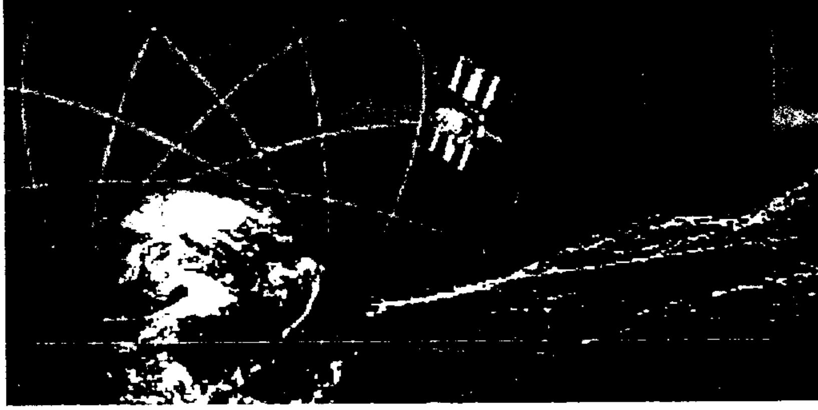
The 24-hour availability of GPS signals provides an infrastructure that is transforming the way that people work and live. GPS is widely used in a variety of applications, such as land and marine surveying; mapping and asset management; land, sea and air navigation; dispatch of public safety vehicles; fleet vehicle management; and agricultural, mining and construction equipment guidance.

Position accuracy of GPS systems for machine guidance applications is now better than 1/10th of a foot (2–3 cm) vertically, by using high-accuracy GPS (RTK differential). This technique uses correction data broadcast from a ground-based reference station at a known location.

For more information about GPS and DGPS, contact Trimble for a copy of "GPS: A Guide to the Next Utility" and "Differential GPS Explained."

About Trimble

Since the company's beginning in 1978, Trimble has been an industry pioneer in developing GPS systems specifically designed for industries such as precision farming, marine, aviation, surveying, mining, and now, construction earthmoving. Trimble's strength lies in developing a deep understanding of industry requirements and producing solutions that significantly increase productivity and cost effectiveness. Offering the broadest line of products with a reputation for the highest level of performance and reliability, Trimble has been named the GPS partner of choice with companies such as Bosch, Caterpillar, Honeywell, Microsoft, Pioneer, Siemens and many others.



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REFERENCES

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International Journal on Public Works, Ports & Waterways Developments

TERRA ET AQUA

A Review of the Past and a Look to the Future

R. Nick Bray

R. Nick Bray

Nick Bray graduated from Cambridge University, UK in 1983. After working for Posford Pavry & Partners as a graduate engineer, he joined Demarok International in 1968. Returning to consultancy in 1973, he practised with Livesey & Henderson, which later merged with Binnie & Partners. In 1989 he formed Dredging Research Ltd and acts as an independent consultant. He is the principal author of Dredging, A Handbook for Engineers, and sits on the Environmental Steering Committee of CEDA.

He was the keynote speaker at the CEDA Dredging Days, November 1997.

Abstract

The paper reviews the changes that have taken place in dredgers, dredging fleets and dredging technology over the past two decades in the light of the changing market for dredging works.The influence of global development in trade and constraints imposed by environmental legislation are also considered.

An attempt is made to determine whether the market leads development or whether development leads the market.

The potential future market for dredging work is also reviewed and the possible developments which might be seen in technology. It is concluded that dredger evolution is generally Darwinian, but that some innovative technological advances may create new markets.The way forward is for the major players to take the environmental aspects of development pro-actively and integrateengineering and environmental solutions.

This paper was the keynote address at the CEDA Dredging Days, held during Europort in November 1997 in Amsterdam, The Netherlands, and was first printed in the Proceedings of the conference.

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Introduction

The international dredging industry operates in a continually evolving global market-place. This is a market where the stalls change in size and type from year to year, and from decade to decade, where at one moment you may find a flurry of activity in one corner and a short time moment you may find a flurry of activity in one corner and a short time later the activity has shifted somewhere else. Meanwhile, the day-to-day trading steadily continues.

For a dredging company to be successful, it must keep a keen eye on the market-place. It must adapt its dredging fleet and technology to keep pace with the trends in the market, or even to precede them, and it must avoid the pitfalls of fleet over-capacity, over-specialisation and over-generalisation. To achieve this fine balancing act is no easy task when you are dealing with such a large and diverse market. It takes good management and a fair degree of luck. Detecting trends and reacting to them is somewhat akin to designing for the effects of global warming. All things are predictable in a deterministic way if we understand the rules that govern the changes. Unfortunately, there are usually too many rules and we only understand a few of them!

However, it may be possible to gain some insight into the future by reviewing the past; perhaps to discover some pointers to the art of survival; a few broad principles which could be used in decision-making. Maybe to answer some basic questions, such as "Does the market lead the technology or does technology lead the market?", and "Can Darwinian theory be used in the study of dredger development?"

In this paper, the changes which have occurred in dredging technology over the last 20 years or so are reviewed. The background against which these changes have occurred is investigated and some thoughts about the future are postulated.

One area which has not been covered is the North American market. Here, owing to certain legislative measures and a monopolistic regime, for much of the period under study, competition and development were stifled. However, in an effort to break free from the environmental stranglehold, the US dredging industry has shown some signs of freeing itself up for development.

General Changes Over the Past 20 Years

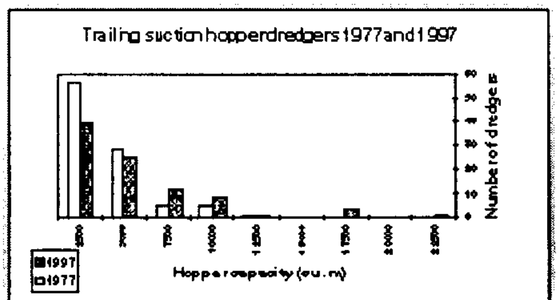


Figure 1. Numbers of trailing suction hopper dredgers in 1977 and 1997.

That fundamental changes have taken place in dredger size and type over the last two decades there is little doubt. For example, Figure 1 shows the size distribution of trailing suction hopper dredgers in 1977 compared to that in 1997. Although the sources from which the numbers in this figure are derived are generally inaccurate and incomplete, it is clear that there has been a massive increase in hopper capacity of individual vessels. However, the true effect of this on the marketplace is not easy to see until one examines the fleet capacity. Incidentally, the number of smaller trailers has probably not fallen. The 1977 figures contain some dredgers which worked exclusively in one port and have not been included in the 1997 figures.

Fleet capacity is defined here as "number of dredgers x hopper capacity" for any particular size category of dredger. The results of this are shown in Figure 2.

As can be seen from this figure, the two largest categories (around 17,500 m3 and 22,500 m3) represent nearly 20% of the total available fleet capacity.

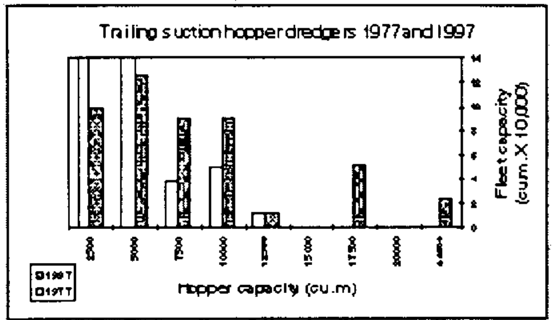


Figure 2. Capacity of the trailing suction hopper dredger fleet in 1977 and 1997.

The large vessels under construction and still to be launched will increase this percentage even further (Figures 3, 4, 5, 6).

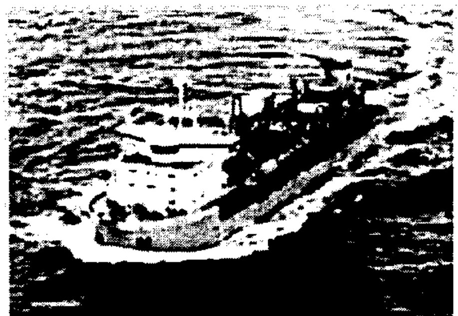


Figure 3. The Pearl River (17,000 m3), built in 1994, is one of the largest TSHDs in the world.

Figure 4. The 18,000 m3 TSHD Amsterdam, launched in May 1996, is shown here at work in Hamburg Harbour, Germany.

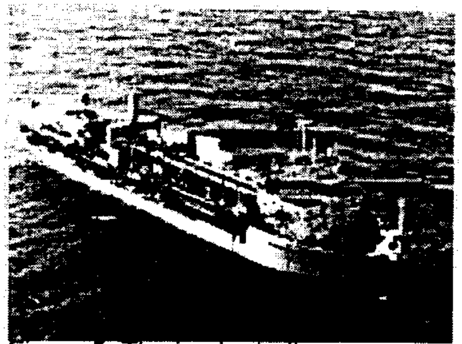


Figure 5. The jumbo trailer Gerardus Meractor (also 18,000 m3) was launched in September 1996.

It can also be seen from Figure 2 that the total fleet capacity has increased overall since 1977. This increase is not quite as large as appears from the graph, because in 1977 most hoppers were designed for a load density of around 1.8 Mg/m3, whereas now many of the hoppers are designed on a load density of 1.4 to 1.6 Mg/m3. For any additional capacity to be usefully employed, either the total amount of work has to increase or the trailers have to obtain a larger share of the market at the expense of other types of dredger.

One way in which the trailers can increase the total amount of work is for them to be capable of carrying out dredging in conditions hitherto not possible for this type of vessel. This aspect is examined later.

Other dredger types also exhibit a marked change in their distributions over the same period. Figure 7 shows the comparison of the numbers of backhoe dredgers available in 1977 and 1997. Here, there has been a marked increase in numbers overall, particularly in the smaller sizes. In terms of the total fleet, the backhoe dredger has probably trebled its capacity.

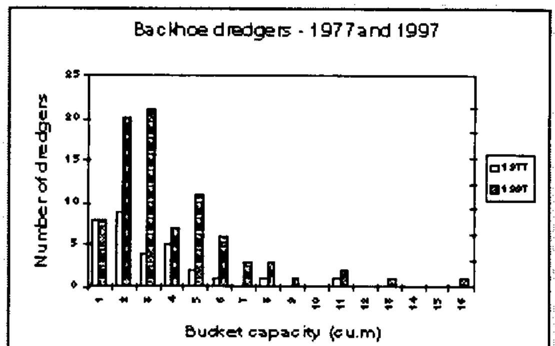


Figure 7. Numbers of backhoe dredgers in 1977 and 1997.

The bucket chain dredger numbers are shown in Figure 8. The smaller sizes of dredger have fallen in numbers to about a third of their original fleet. However, as the dredgers become larger so the numbers have been maintained, until one reaches the 800 to 900 litre bucket size where the capacity has changed little over the intervening years. This is probably owing to the fact that the larger bucket dredgers are used for dredging appreciable volumes of strong soils, which they are capable of doing at economic rates compared with backhoes.

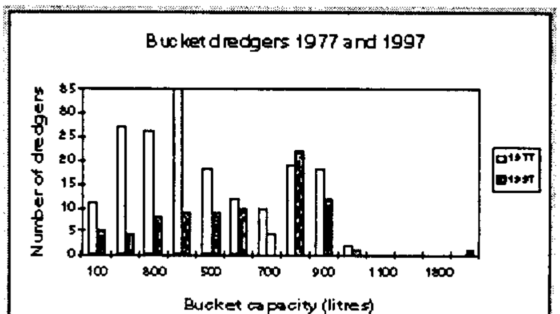


Figure 8. Numbers of bucket dredgers in 1977 and 1997.

Grab or clamshell dredgers have suffered the same fate as the bucket dredger (see Figure 9). Here the numbers of the smaller sizes have reduced considerably, whilst the larger grabs have increased in numbers. There is even a 200 m3 capacity grab dredger in Japan, which has not been shown. Clearly, use has been found for the larger sizes of grabs whilst the smaller grabs have been largely superseded by another type of dredging method.

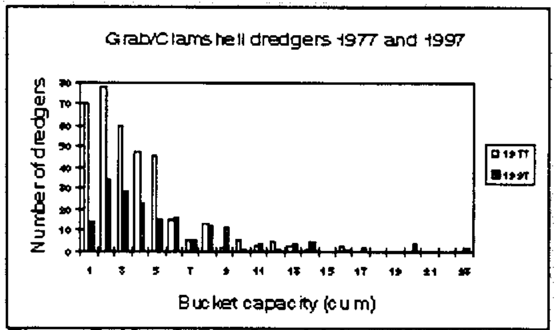


Figure 9. Numbers of grab/clamshell dredgers in 1977 and 1997.

It is difficult to draw firm conclusions from the numbers shown above, because of the numerous factors involved and the unreliability of the reporting of numbers. However, it is probable that, in some respects, they may be explained by the following:

a. Dredging of weak soils
   The trailer dredger has become much more efficient at dredging weak soils and has extended its capability into soils of greater strength. When working in harbours in a maintenance capacity, and particularly when used in conjunction with a bed leveller, it has replaced the grab dredger and the bucket dredger.
b. Dredging of strong soils
   The bucket dredger still dredges strong soils, when volumes are large. When volumes are small the backhoe is more likely to be economic. Very large grabs may also be used for firm soils, particularly when sea conditions prevent bucket dredgers and backhoes from working.

It will be noticed that cutter suction dredgers have not been mentioned in the above analysis. This is because the number of cutter suction dredgers has not changed significantly over the last 20 years. However, their characteristics have changed and are described below.

Trailing Suction Hopper Dredgers

The main changes in trailer dredgers over the last two decades, apart from the considerable increase in hopper capacity, are as follows:

a. On the suction side, degassing systems have become more reliable and have enabled higher density mixtures to be dredged during maintenance dredging. Pumps in the dragarm have also contributed to higher density mixtures and dredging at much greater depth.
b. In the hopper, overflow weirs have become adjustable, allowing vessels to change their characteristics to suit either sand or silt/mud dredging, and to adopt more sophisticated loading techniques. There has been a marked decrease in the ratio of hopper carrying capacity to hopper volume.
c. Discharge systems have become more adaptable. Many trailers now have a pump ashore or rainbowing capability as well as the conventional bottom discharge. Some are able to discharge through the suction pipe for such operations as covering pipelines. More environmentally acceptable methods of overflowing have been developed.
d. On the bridge, considerable improvements in monitoring and control have been introduced. Positioning, tracking and draghead control are now sophisticated operations. Dynamic

positioning systems have improved efficiency in temporary positioning situations.

e. Overall, costs have been reduced by reducing manning levels and making machinery more efficient.

Figure 10 shows the current normal characteristics of trailer dredgers. It is interesting to note that, in spite of the large increases in hopper capacity, the laden draughts of the larger vessels are not appreciably greater than the smaller trailers. This is partly explained by the lower load carrying capacity of the hopper.

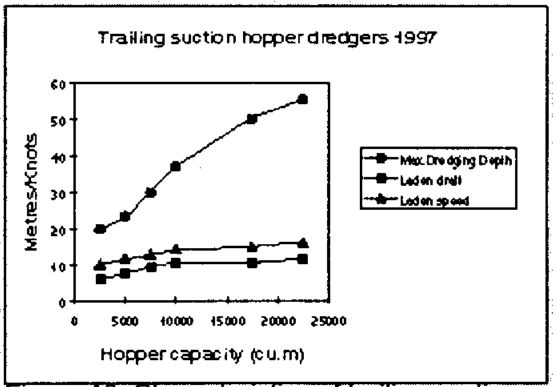


Figure 10. Characteristics of trailing suction hopper dredgers in 1997.

Cutter Suction Dredgers

Cutter suction dredgers went through some evolutionary changes in the later 1970's and early 1980's, mainly as a result of the boom in the Middle East, where many projects involved the dredging of sands, silts and rocks, to be used in reclamation. The effect of this market is illustrated in Figure 11. In this graph, the massive increase which occurred in cutterhead drive and pump power may be seen. These powers are necessary for the dredging and pumping of rock.

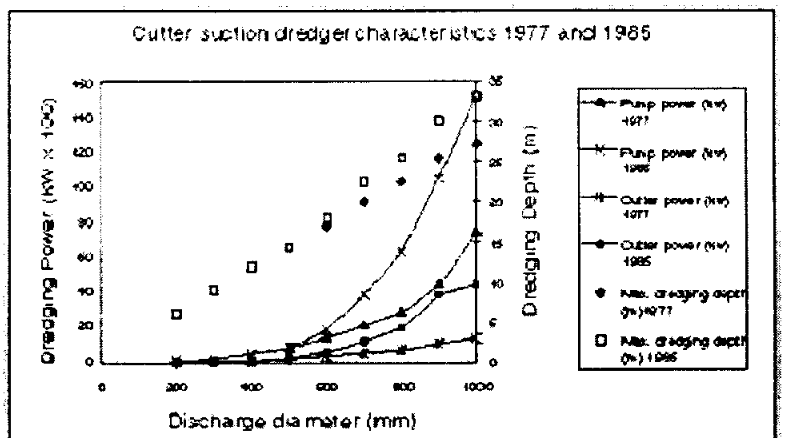


Figure 11. Characteristics of cutter suction dredgers in 1977 and 1985.

Also noticeable in the graph is the increase in dredging depth achieved by the use of ladder pumps in the larger dredgers. Unfortunately, as the Middle East activities slowed down, very little cutter suction work emerged elsewhere. This resulted in an overcapacity of the heavy duty rock cutters.

The main changes in cutter suction dredgers over the last 20 years may be summarised as follows:

a. the introduction of self-propelled cutter suction dredgers for the larger sizes, which considerably reduced mobilisation costs;
b. the introduction of ladder pumps to improve concentration in the deeper dredging depths;
c. the introduction of anti-abrasion materials in pump and pipeline

systems to reduce wear and tear;
d. the development of faster cutter tooth changing, cutterhead changing and spud movement owing to improved systems;
e. automation of the dredging controls to improve accuracy and productivity (some dredging systems can now anticipate the soil conditions by remembering the conditions on the previous cutting swing); and
f. reducing costs by reducing crew numbers and making the mechanical and electrical systems both fuel- and maintenance-efficient.

Backhoe Dredgers

Twenty years ago the custom-built backhoe was relatively rare. It is now treated as one of the main classes of dredger and has emerged as a suitable workhorse for strong soils, such as glacial tills, and for dredging fragmented or friable rocks.

There has not been much development in the basic excavator and its support platform. Power has increased and controls have become centralised.

Positioning and control of the bucket have improved because of electronic positioning and bucket location systems. Land-based backhoes, used for dredging inland waterways, have been developed to improve reach and a number of low-ground pressure and amphibious versions are now available.

Other Developments

The above sections have described the changes which have taken place in the numbers and designs of the traditional items of dredging equipment. However, as one would expect in an innovative and competitive industry, there have been a number of new developments and designs which have been introduced in the last two decades. It would be impossible to describe all of these. A few of particular note are illustrated here.

Water injection dredging

The water injection dredger, a proprietary design, is fundamentally different from other items of dredging plant. This dredger, illustrated in Figure 12, fluidises material on the sea or river bed, thereby encouraging the material to form low level density currents which move into deeper water. The system has found many applications and is one of the few really novel designs to have proved of wide practical use for the dredging of "clean" materials.

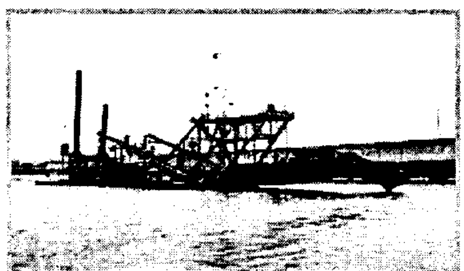


Figure 12. Through this artist's rendering underwater, the unique design of the water injection dredger Jetsed can be seen.

There may well be environmental problems to be overcome in the use of the water injection system for the maintenance dredging of large volumes of material. However, it is possible that its low cost may encourage the development of more frequent and environmentally friendly maintenance dredging campaigns which involve the fluidisation of small and more acceptable volumes of sediment for dispersal into the local environment.

Much of the success of this system will depend on the ability of engineers to establish the baseline environmental characteristics of their dredging sites in a comprehensive manner and to predict and monitor the effects of the water injection works.

Environmental/restoration dredgers

The other area which has seen a proliferation of innovative ideas, driven by necessity, is in the field of environmental/restoration (or remedial) dredging. In this field it was soon recognised that benefits accrued to the company which could produce a dredger that was accurate (thereby reducing overdredging) and minimised the suspension of bed materials. A great variety of developments has emerged, many as attachments to standard items of plant. A number of these are mentioned below:

a. Backhoe dredgers: Closed buckets such as the Visor Grab, which closes the bucket, thereby preventing loss and compression of the material. Also the screening bucket which coarse screens the dredged material as it empties.
b. Grab dredgers: The Cable-Arm closure clamshell bucket, which minimises overdredging and prevents overflowing of the bucket.
c. Bucket chain dredgers: Sound-proofing, enclosing the ladder, valved buckets to prevent air escaping at bed level, bucket cleaning.
d. Suction dredgers: Environment-friendly cutterheads, the Matchbox suction head, the Scoop- and Sweep-heads (Figures 13 and 14), the disc cutterhead (Figure 15), the closed auger (Figure 16), all designed to minimise turbidity generation.

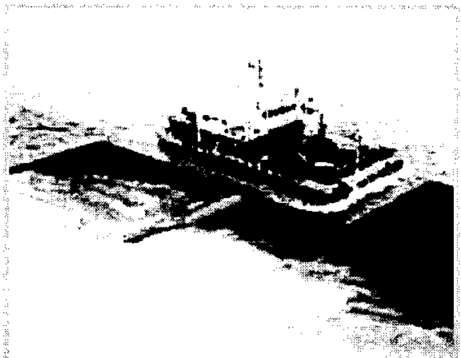


Figure 13. The scoophead reduces turbidity during dredging.

Figure 14. The cutter dredger Vlaanderen XV has been rebuilt with a sweephead, an environmentally friendly dredging system.

Figure 15. Close up of the environmental disc cutter installed on the Vecht.

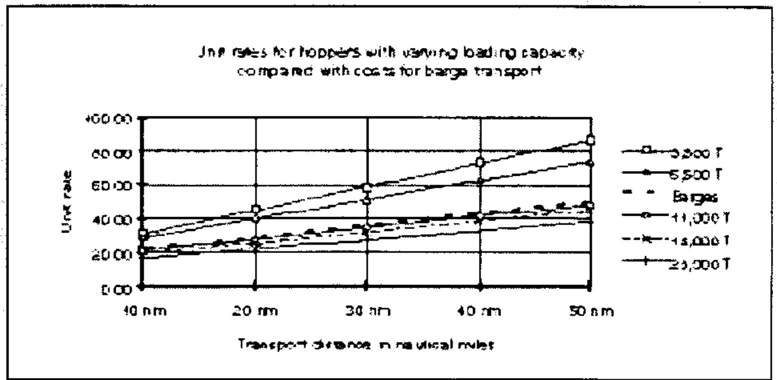


Figure 16. The closed auger, Willem Bever, has been used to dredge in highly contaminated waters.

e. Positive displacement pumps: All designed to pump dredged material at its in situ density, thereby reducing volumes for transport and disposal.
f. Trailing suction hopper dredgers: The re-circulation of overflow water by feeding to jets at the draghead, thereby reducing the quantity of overflow being discharged to the site. This is a proprietary system developed by Royal BosKalis Westminster.

The Dredging Market

The world dredging market is huge and diverse and it is not possible to analyse it in detail in a paper such as this. However, a few broad points can be made.

Over the last five years the dredging market has been dominated by activities in South East Asia, particularly in Hong Kong, where reclamation works associated with the Port and Airport Development Strategy and Metroplan have involved the movement of around one billion cubic metres of dredged material. Developments such as these show no sign of tailing off in Hong Kong or in the region as a whole. Already, there are plans for further massive land reclamation works in Singapore, Malaysia and Taiwan, with one such project requiring around 200 million m3 of fill. With figures like this in mind it is not difficult to see why dredging contractors are confidently building large trailers.

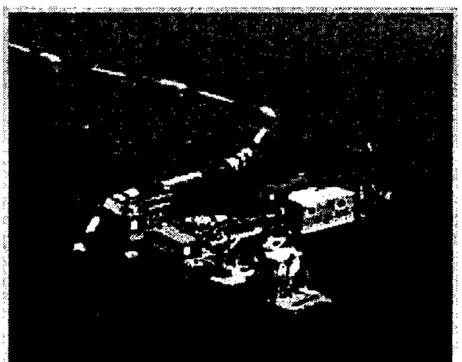


Figure 17. Cost of dredging, transporting and dumping : trailer dredgers 1997

To demonstrate the reason for this confidence, it is merely necessary to examine the costs of dredging sand, transporting to a site and dumping. Figure 17 shows the results obtained for a mythical project for various sizes of trailer. It also shows the costs associated with dredging by stationary dredger and transporting by barges. There are two key points shown by this figure; the larger trailers are cheaper than barge transport and the larger trailers are making the supply of sand cheaper in absolute terms. Hence, to compete with conventional equipment (dustpan/grabs and barges) it is essential to have trailers of over 14,000 m3 capacity.

It is also possible that the reduction in absolute sandfill cost will increase the market volume, as the marine dredged sand becomes more acceptable than that from an equivalent land-based source. The graph in Figure 17 might be very different under different circumstances, where for instance total sand volume, water depths, environmental constraints and other factors varied, but it serves to illustrate the points.

In the Middle East, where activity has been relatively steady over recent years, there still seems to be a modest base load of dredging and reclamation works, generally associated with industrial ports and waterside leisure developments. This work has traditionally been executed by heavy-duty cutter suction dredgers and there is no reason to doubt that these machines will continue to carry out the bulk of the future work of this type.

In western Europe the market is likely to be dominated by coastal engineering works and port developments. So-called "soft engineering" solutions to coastal problems, involving the re-charge of beaches with sand or gravels, have been the fashion for a few years now and are likely to continue for the foreseeable future. Although not massive, the volumes of dredging involved add an appreciable workload for trailer dredgers.

European ports are beginning to deepen their access channels and berths again to maintain competitiveness, particularly in the container trade. Adding another 2 metres to an existing navigable depth frequently represents a sizeable dredging project; work which may be carried out by trailer, backhoe and bucket dredger.

The deepened ports may also require additional maintenance. More work for trailers! If European container terminals are getting deeper, it is probable that container ports in the rest of the world will be developing in a similar fashion and that more capital dredging will occur.

Some of the South American economies have seen formidable growth rates in the past five years. Although the west coast of South America is not likely to generate massive dredging works, there being few substantial rivers on that side of the continent and deep water relatively close inshore, the situation on the east coast is very different. Large rivers and estuaries exist and a considerable amount of trade depends on river transport, estuarine ports and dredged channels. It is likely that trailer dredgers could be gainfully employed in these areas for some time to come.

In summary, therefore, it would appear that, in the short to medium term there is sufficient work for trailing suction hopper dredgers and backhoe dredgers. Cutter suction dredgers will not be in huge demand, but a base load of work will probably continue. Innovative dredgers for special projects and remedial dredging will continue to be in demand.

Future Trends

The evidence from the above discussion of dredger types and changes over a 20 year period is that, in general, dredger development has followed the market. The one development which might be seen to have not been market-led is the introduction of water injection dredging. This dredger may, to some extent, be making its own market.

The dredging market itself is affected by two major, but often opposed, factors; trade and the environment. Almost all dredging projects relate to one or both of these factors. Trade encourages people to move goods around the world and leads to the need for new ports, deeper ports, industrial ports, infrastructure, new land and leisure facilities. Environmental legislation affects the way projects are carried out. It controls use and disposal of dredged material. It affects the methods of dredging. It affects the way engineering is carried out and this, in turn, may determine whether dredging is required or not, and how it may be executed.

For example, the whole question of development in estuaries. How is it best to modify an estuary?

By dredging large volumes over short time periods and taking the dredged material to sea, or dredging small volumes over very long periods and trickle feeding the material back into the estuary?

In coastal engineering, should we build "hard" or "soft" defences? Should we build ports out to sea or dredge basins inland?

If we want to predict the future volume of dredging we need to look at world trade. If we want to predict the form of dredging projects, we need to look at trends in the way that the engineering world is adapting to the requirements set by our environmental legislators. These will give us pointers towards the types of dredgers we need in the future.

Historically, there have always been two main driving forces behind innovation in dredging; reducing dredged volume and reducing unit costs. These two forces remain. Speculating about what might happen to dredgers in the next few years might lead to the following suggestions:

For trailers:

- the development of on-board mixture handling processes designed to increase the density of the dredged material in the hopper
- the introduction of more devices to reduce overflow plumes
- greater control over draghead position.

For cutter suction:

- systems for reducing the amount of low density water passing down the pipeline.

Generally:

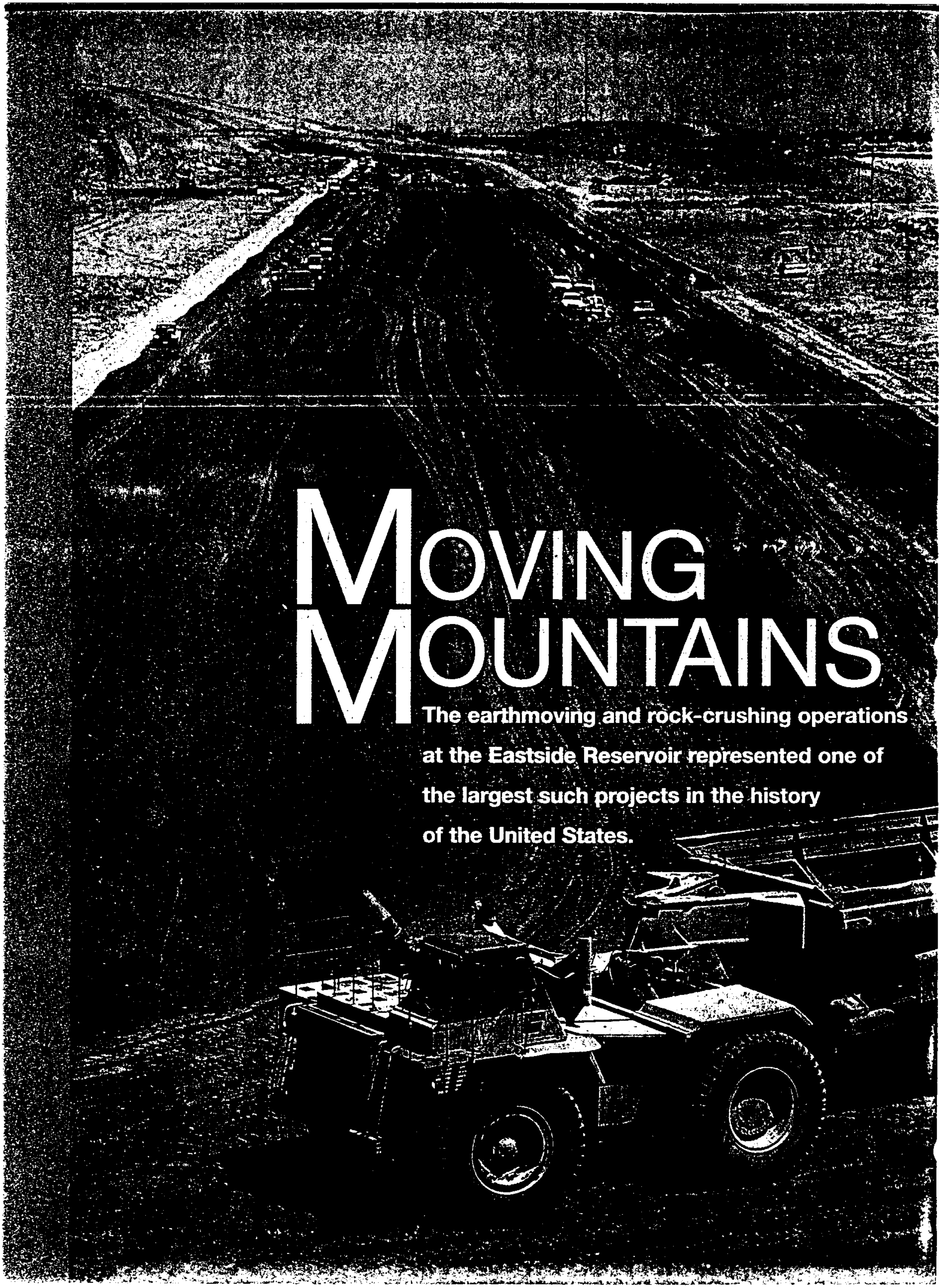
- further increases in pump and engine efficiencies
- more automation
- possible return to simpler "agitation" type dredging methods, if baseline measurement of site and environs is improved.

Conclusion

In general, it may be said that the evolutionary process of dredger development is Darwinian, i.e. companies which adapt their fleets to have the most suitable plant and the right mix of plant will survive. However, it is possible to create a new market and the water injection dredger may be just beginning to show us this.

Further innovative dredger designs may yet appear to enable other new markets to be developed. But the question which arises is "how do you identify the potential markets?" This may be answered by studying the two driving forces; trade and environment. In particular, the environmental solutions to developments necessitated by trade may give some useful pointers to where we should be looking in the future.

If one accepts this, then it might not be too strange in the future to find environmental scientists in the research and development departments of major dredging companies. This would then enable teams to put forward comprehensive solutions to development needs, by introducing new techniques which have been evolved against an environmentally sound background. It has already happened in the field of dredging for inland waters.



MOVING MOUNTAINS

The earthmoving and rock-crushing operations at the Eastside Reservoir represented one of the largest such projects in the history of the United States.

S. MILLER, A. KIMBELL, M. TUCKER AT MWD, ALL PHOTOGRAPHS

The Eastside Reservoir's three earth and rock-fill dams required unprecedented amounts of equipment for loading, hauling, and compacting embankment materials to meet the three-and-a-half-year dam construction schedule. The reservoir's construction field operations were the largest ever in the nation, moving 150 million cu yd (114 million m³) of materials to construct the 110 million cu yd (84 million m³) of embankment—more than twice the total excavation of the Channel Tunnel, which links the United Kingdom and France.

Joseph L. Ehasz, P.E.,
Steven D. Summy,
Paul R. Zaman, P.E., and
Dennis G. Majors, P.E.

To complete the project, the 1,800 members of the construction team worked in two 10-hour shifts on weekdays and two 8-hour shifts on Saturdays between March 1996 and December 1999. Each day more than 50,000 tons (45,360 Mg) of excavated material was crushed to produce the required size for placement in the dam embankments. More than 225 compactors, front-end loaders, front-shovel loaders, dump trucks, bulldozers, graders, and water trucks were on the job, ranging in weight from 27 to 350 tons (24 to 318 Mg). All told, the equipment traveled 720 mi (1,158 km) and consumed 48,000 gal (182,000 L) of fuel each day. Project construction activity costs totaled about $1 million per day.

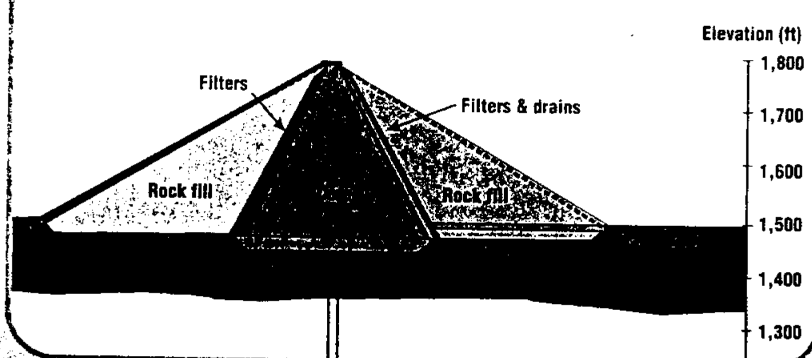
About 70 percent of the embankment cross section for each of the three dams consists of rock fill. The central core, which represents about 20 percent of the embankment, consists of clay and impervious material. The remaining 10 percent consists of processed rock material for the filters, drains, and transition zones. These percentages translate into 75 million cu yd (57 million m³) of rock fill, 25 million cu yd (19 million m³) of core material, and 10 million cu yd (7.6 million m³) of processed rock and riprap. The peak placement rates exceeded 250,000 cu yd (191,200 m³) per day.

All of the earth and rock required for the dams came from within the project area. The center zone of each embankment consists of densely compacted earthen material excavated from the valley floor. The outer shells of the dams consist of rock up to 2.5 ft (0.8 m) in diameter that has been compacted to give the embankments their strength. The rock comes from the hills surrounding the reservoir. The zones between the dam shells and the core include upstream and downstream filters and transitions to protect the core and ensure that the impervious material stays in the core zone (see figure 1). Downstream drains will intercept water that will unavoidably seep through. Materials suitable for the filters and drains—in sizes ranging from sand pebbles to rocks 6 in. (150 mm) in diameter—come from hard quartzite excavated from the hills.

The mountains along the south side of the reservoir—the source of the fill materials—vary geologically from quartzite rocks in the west to gneiss at the eastern end of the project. These mountain formations provided more than 90 million cu yd (69 million m³) of rock material for the dams. The remaining 20 million cu yd (15 million m³), which was used for the central core zone, was dug from the alluvial soils in the valley floor.

The contractors used large mining equipment to excavate and haul the rock materials. The drilling equipment in the quarry drill and blast operations produced enough 6 in. (150 mm) holes to generate 125,000 cu yd (95,600 m³) of material each day. One blast at each end of the valley occurred daily. The largest contained more than 200,000 lb (90,720 kg) of explosives.

Fig. 1 Embankment Cross Section



The loading in the rock borrow areas involved five hydraulic shovels with 22 cu yd (17 m³) buckets—three at the West Dam and two at the East Dam. The shovels could load at peak rates that exceeded 1,700 cu yd (1,300 m³) per hour. Additional loading power was provided by 15.5 and 26 cu yd (11.9 and 20 m³) front-end loaders.

Heavy mining equipment was also used in moving the rock material from the borrow areas to the dams. More than 40 large-haul units were used to make the 2 to 4 mi (3.2 to 6.4 km) trip to the embankments at speeds up to 40 mph (64 km/h) and payloads ranging from 90 to 200 tons (82 to 181 Mg).

BELLY DUMPS *placed material for the East Dam core zone in windrows to facilitate spreading and compaction in 8 in. (200 mm) lifts.*

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The spreading and compaction on the embankment had to match the rate of incoming rock-fill material. The large bulldozers each weighed more than 100 tons (91 Mg) and spread a 200 ton (181 Mg) load of rock fill in two passes. The hauling and spreading activity of the heavy trucks and bulldozers compacted the rock fill before the compactors went into action. The large dump trucks, which weighed 275 and 350 tons (250 to 318 Mg) when full, and the spreading dozers did most of the compaction and consolidation of the rock-fill material. Rock-fill densities of 140 to 150 lb/cu ft (2,243 to 2,403 kg/m^3) were consistently achieved with little effort from the smooth-drum vibratory compactors.

SIDE-CUTTING BELT *loaders cut a 10 to 20 ft (3 to 6 m) high face from the alluvial soil borrow and stockpile areas and loaded the material into the belly dumps for placement in the core zone,* top. *More than 110 million cu yd (84 million m^3) of embankment material are being used in the three dams, which seal off a 4.5 mi (7.2 km) long valley,* bottom.

The impervious materials used for the core zones of the dams also were obtained from within the reservoir area. These materials are the alluvial clayey sands and silty sands from the valley floor. Rates of core placements for the dams at the site ranged from 50,000 to 80,000 cu yd (38,240 to 61,184 m^3) per day.

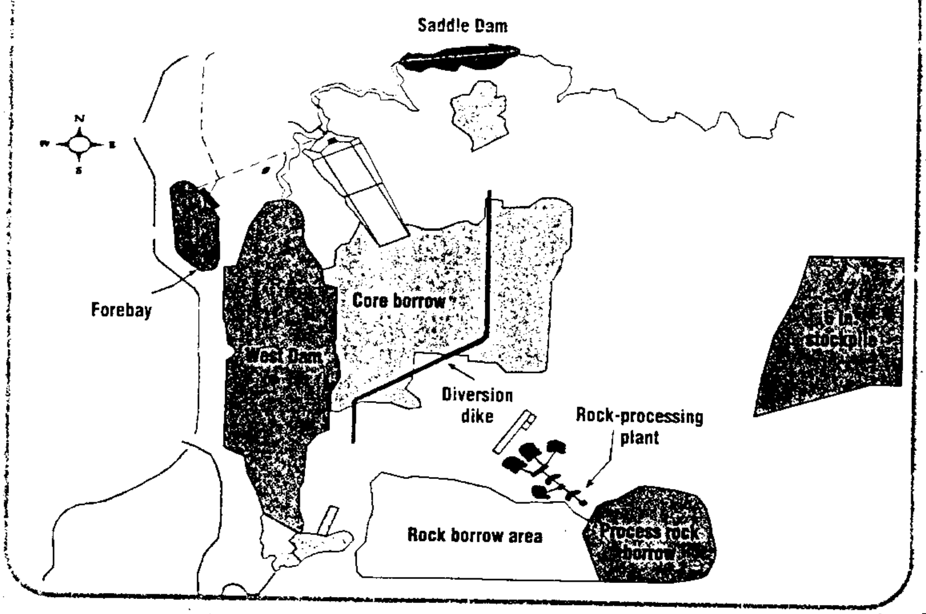
The core zones were formed from materials stockpiled from the dam excavations and from the impervious borrow areas immediately upstream of the dams. Since these materials were alluvial deposits comprising vertically stratified clays, silts, and sands, it was important to blend the materials before placing them in the core zone of the dams. To achieve this blending, as well as high production rates, side-cutting belt loaders powered by two high-capacity bulldozer tractors were used to excavate the materials. The machines cut a 10 to 20 ft (3 to 6 m) high face of alluvial material and loaded it into 120 cu yd (92 m^3) belly dump trailers at the rate of 1.0 to 1.5 cu yd (0.8 to 1.1 m^3) per second.

The belly dumps moved the material along the 2 to 4 mi (3.2 to 6.4 km) haul distance at speeds of 35 mph (56 km/h) and grades of 8 percent. The trailers placed the impervious materials on the core zone of the dam in windrows to facilitate spreading and compacting in 8 in. (200 mm) lifts. Again, the action of these large, heavy units helped to compact the core zone.

The prime contractor for each dam project was responsible for processing more than 24 million tons (22 million Mg) of rock to support embankment construction. Construction of the West and Saddle dams was carried out under a contract separate from that for the East Dam. The designated limits of the borrow area for the processed rock did not afford adequate area for two separate contractor operations at the same time. Therefore, the West Dam contractor developed the quartzite rock borrow area and produced the source materials to be used for processing filter and drain materials for all three dams (see figure 2).

The rock-crushing plants operated by the two contractors were required to produce four types of processed rock: coarse filter (transition material), upstream filter, downstream filter, and drain material. Each plant had a different design capacity, as dictated by the demands of the two construction contracts. The estimated total volume of processed filter and drain materials for the West and Saddle dams was 6 million cu yd (4.6 million m^3). Similarly, the estimated total volume of processed materials for the East Dam contract was 4 million cu yd (3 million m^3).

Fig. 2 Borrow Area for West Dam and Saddle Dam



The West Dam rock-crushing plant was designed with four stages to reduce the 48 in. (1,220 mm) rock to usable sizes. The primary crushing stage reduced the blasted, pit-run material to 12 in. (300 mm) or less using two crushers with a combined design capacity of 3,200 tons (2,900 Mg) per hour. Two gyratory crushers in the secondary stage also had a combined design capacity of 3,200 tons (2,900 Mg) per hour and produced rock that was 6 in. (150 mm) or less. Output was conveyed to a surge pile, reclaimed, and hauled to the tertiary process. Coarse filter material was produced in this stage either by screening the 6 in. (150 mm) crusher-run product reclaimed from the surge pile or by screening the 6 in. (150 mm) product of two cone crushers. The design capacity through the tertiary stage was 2,000 tons (1,814 Mg) per hour and averaged 1,500 tons (1,360 Mg) per hour.

The through product, that is, material not retained in the coarse filter stockpile, was 2 in. (50 mm) or less and was conveyed to a surge pile, from which it was reclaimed and conveyed through a two-step screening process to produce drainage layer material and part of the upstream filter. To produce downstream filter and the rest of the upstream filter, the material was passed through the vertical-shaft impact crushers, dry and wet screens, and sand screws.

The rock-crushing plant installed by the East Dam contractor reclaimed 6 in. (150 mm) materials from the 12 million ton (11 million Mg) stockpile furnished by the West Dam contractor. The East Dam crushing plant had two crushing stages. Coarse filter and drain material were produced in the primary stage. The primary feed capacity from the 6 in. (150 mm) stockpile was 1,800 tons (1,633 Mg) per hour. The input was divided and fed into two 8 by 24 ft (2.4 by 7.3 m) triple-deck shaker screens. The output from these two screens was conveyed directly to the coarse filter zone, fed into two cone crushers that produced drain material, or placed on two surge piles and used in the secondary crushing and processing stage. The design production rates for coarse filter and drain material were 700 and 300 tons (635 and 272 Mg) per hour, respectively.

Material for the upstream and downstream filter zones was produced in the secondary stage of the plant, which had a design capacity of more than 700 tons (635 Mg) per hour. The secondary crushers included three cone crushers and two vertical-shaft impact crushers. The output of the three crushers passed to a bank of six 6 by 20 ft (1.8 by 6.1 m) triple-deck shaker screens. Here the coarser material was used in the upstream filter and the finer material was conveyed for wet screening, washing, and classification in the material density separators to produce the downstream filter material and the fines for the upstream filter material. The design production rates for the two types of filter material were 300 tons (272 Mg) per hour each.

The materials for the Eastside Reservoir project were drilled, blasted, crushed, loaded, hauled, placed, and compacted at an unsurpassed rate in the dam construction industry. The shovels, loaders, and trucks used on the project are the largest available in the industry and establish a new standard for earth and rock movement. The two rock-processing plants provided a combined production that exceeded the capability of any single commercial processing operation in California. ▼

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Panama Canal: Passage to 2000

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By John C. Gribar, P.E., and Jaime A. Bocanegra.

On New Year's Eve the United States turned over ownership and operation o Panama Canal to the Panamanian government. In preparation for this transfe $1-billion modernization and rehabilitation program has been implemented to improve the canal's operation. The next frontier will involve supplying the wate necessary to support the expected increases in traffic.

The Panama Canal Treaty, which was formalized on September 7, 1977, by t United States and Panama, sets noon, December 31, 1999, as the date the United States will transfer ownership and operation of the canal to the Panamanian government. Signed by President Jimmy Carter and General Om Torrijos, the treaty went into effect on October 1, 1979, creating the Panama Canal Commission as an independent U.S. government agency that would he implement organizational structures in accordance with new Panamanian regulations and transfer property without a complex approval process. The two-decade period that followed provided time for the closure of U.S. military bases, the withdrawal of more than 10,000 troops, the transfer of property and assets occupying more than 500 sq mi (1,295 km2) of land, and the preparati of new laws and regulations.

To establish what should be done to the canal before the handover, the Pana Canal Commission, the organization overseeing the modernization and rehabilitation project, engaged the services of the U.S. Army Corps of Engine in August 1995 to assess the canal's current operating condition. Results of th 18-month study, combined with ongoing canal studies and previously identifie improvement needs, formed the basis of the $1-billion modernization and rehabilitation program that is now in progress. The objectives of the modernization and rehabilitation program are to increase the canal's operating capacity by 20 percent, make it more reliable and efficient, provide greater margins of safety, and decrease maintenance costs. The modernization and rehabilitation program will continue unaffected by the New Year's Eve transfe and will be completed in 2005.

In 1994 Panamanian lawmakers approved a constitutional amendment that established the Panama Canal Authority as an independent agency that woul responsible for the operation and management of the waterway upon transfer The constitutional provision and accompanying legislation call for a budget ba on self-generated revenues and the transformation of the canal agency into a more competitive and customer-oriented corporation. The law also guarantee the employment of the current labor force and establishes working conditions similar to those under U.S. administration. Today, Panamanian citizens make more than 95 percent of the canal's 9,000-strong workforce, making the cana one of the largest employers in Panama.

A 1996 law signed by President Bill Clinton transformed the Panama Canal Commission into a government corporation, a move that has fostered a more business-oriented administration of the canal.

Engineers as well as laymen have long recognized the design and constructio this 50 mi (80.5 km) long waterway as one of humanity's greatest engineering achievements, despite the fact that its construction claimed many lives. The Spanish envisioned a canal across the isthmus as early as the 1500s, but it w the French who set the dream in motion when Ferdinand de Lesseps, the buil of the Suez Canal, began construction in 1880. De Lesseps greatly underestimated the magnitude of the effort, however, and lacked the organiza and machinery needed to advance the work. Tropical disease was one of his greatest obstacles, but financial problems finally vanquished his dreams in 18

The Spanish American War (1898) persuaded President Theodore Roosevelt that the United States needed control over a canal in the Western Hemispher protect its military and trade interests. The Hay-Bunau-Varilla treaty, which wa signed in 1903 by Panama and the United States immediately after Panama declared independence from Colombia, obligated the United States to defend Panama's sovereignty and gave the United States the right to build a canal across the isthmus. The treaty established the Panama Canal Zone, a 10 mi (km) wide strip of land controlled by the United States stretching from the Atlan to the Pacific and dividing Panama in half. Canal construction further defined geographical divide, and even today only one permanent bridge unites the tw sections.

More than 830,000 ships have traversed the canal since its opening on Augus 15, 1914. The canal has undergone very few changes, the exceptions being t construction of a second reservoir in 1935 to increase and improve control ov water resources and the widening and deepening of the channel to accommo the ever-increasing sizes of commercial ships.

The Panama Canal is located at the Isthmus of Panama's narrowest point, wh also offers the lowest topographic relief. It takes advantage of a natural watercourse, the Chagres River, to form a large reservoir called Gatun Lake. reservoir stores water used for gravity-flow canal operations and forms part o canal channel. The canal was originally planned as a sea-level canal, but its second chief engineer, John F. Stevens, decided to use locks instead, reason that the region's heavy rainfall would supply sufficient water. Each two-lane lo chamber, made entirely of concrete, is 110 ft (34 m) wide and 1,000 ft (305 m long and accommodates ships up to 39.5 ft (12 m) in draft. One set of locks li ship arriving from the Atlantic Ocean in three steps to a maximum of 87.5 ft (2 m) above sea level into Gatun Lake. After traveling 23 mi (37 km) across the lake, the ship must navigate seven curves in the 8.5 mi (13.7 km) long Gaillar Cut, the narrow portion of the canal that crosses the Continental Divide.

On the opposite side of the canal, a double set of locks lowers the ship in thre steps back to sea level into the Pacific Ocean. Transit typically takes about 10 12 hours and the toll averages $43,000. A vessel passing through all three se of locks requires the release of 52 million gal (196,820 million m3) of water fro the lake, half into each ocean.

Canal operations are entirely dependent upon toll revenues and some hydropower and potable water sales. The Panama Canal Commission owns a water purification plant as well as the Gatun and Madden hydroelectric dams. told, canal operations generate about $700 million per year, and there is no funding from the U.S. government. All improvements, including the current modernization and rehabilitation program, are being funded by canal revenue About $450 million has been spent on the program so far, and regular maintenance costs about $255 million per year. In fiscal year 1998, which beg on October 1, 1997, more than 13,100 oceangoing vessels traversed the cana local vessels are counted, the figure rises to 14,500.

The major components of the modernization and rehabilitation program are th widening and straightening of the Gaillard Cut; the purchase of new tugboats locomotives (electric engines that position ships laterally as they enter and m through the locks); the replacement of about 10 mi (16 km) of locomotive trac the installation of hydraulic cylinder arms for operating the lock gates; and the implementation of a new vessel traffic management system.

The widening of the Gaillard Cut, the centerpiece of the modernization progra was initiated in 1991 and originally scheduled for completion in 2014. A drama increase in traffic in 1995, combined with a 1997 study predicting continued increases, prompted Alberto Aleman Zubieta, the administrator of the Panam Canal Commission, to move the completion date forward to 2002. The accelerated program is being funded by increased tolls: in 1996, the commission's board of directors approved two toll increases-an 8.2 percent ri that went into effect in January 1997 and a 7.5 percent hike that kicked in the following January.

The Gaillard Cut is, however, a problematic section of the canal in that it is pr to landslides. The commission guards against landslides by building terraced slopes along the canal's banks, checking in situ motion sensors for land movement, and monitoring groundwater pressure. To assess this pressure, c personnel insert electronic probes-piezometers-into plastic-lined holes scatter along the banks. These instruments use the conductivity of water to indicate t level of the groundwater.

The project is widening the cut channel from 500 ft (152 m) to a minimum of 6 ft (192 m) along straight stretches and to 730 ft (223 m) along curves. These modifications will allow the largest ships (wider than 106 ft [35.5 m]) to travel simultaneously in two directions, eliminating the periodic lulls in lock operation that occur while operators wait for the last northbound vessel (Pacific to Atlan to pass and the first southbound vessel to arrive.

At an estimated cost of $218 million, the cut widening calls for the removal of some 44 million cu yd (33.7 million m3) of material.

Workers have created a 130 ft (40 m) wide bench, or terrace, from which to perform the excavation 3 to 5 ft (0.9 to 1.5 m) above the waterline. The mater then trucked to waste disposal sites previously assessed for their environmen impact, usually 1 to 2 mi (1.6 to 3.2 km) away. Workers position hydraulic backhoes on the benches and excavate as far as the equipment can reach, a 20 ft (6 m). The wet material is brought up and trucked to disposal sites. A dik holds the deposited material in place, and a culvert-type spillway that works m like a weir controls drainage. Next, a floating, rotating-cutterhead suction dred removes soft material lower down, which is pumped through a series of steel pipes to disposal sites up to 2 mi (3.2 km) away.

To remove underwater rock, four barge-mounted tower drills 80 to 90 ft (24 to m) high drill holes. Workers insert plastic tubing into the holes and pack the h with dynamite. Sounding devices tell drill operators how deep they are cutting Blasting occurs once or twice every two weeks, once several sites have been prepared. A 15 cu yd (11 m3) bucket dipper dredge removes the rock and pla it in bottom-dump scows for disposal in deep portions of Gatun Lake. The dry excavation portion is now 91 percent complete; the wet excavation, 50 percen complete.

Another modernization project involves the installation of hydraulic cylinder ar to operate the 80 lock gates and water-control valves. All gates are of the mite type, meaning that the leaves come together in the center to form a V. There built-in redundancy, with double sets of gates at each end. In addition, a doub set near the middle separates the locks into 600 ft (183 m) and 400 ft (122 m) chambers. The intermediary gates were used more when ships were smaller; operators would fill only the smaller chamber with water, saving time and preventing unnecessary water from being flushed into the ocean. Today smal ships are usually scheduled to use the locks in pairs, requiring that the whole be filled. The new hydraulic system is more efficient than the current, 1914-er electromechanical one, and because it has fewer moving parts, it is more relia and requires less maintenance.

Other projects include new tugboat and locomotive purchases and a state-of-the-art vessel traffic management system. Officials began buying sev new tugboats in 1996 at a total expected cost of $46.7 million. After the purchases are completed in 2005, the fleet will number 24 units. Tugboats es large ships through the Gaillard Cut as a safety precaution and help position ships as they enter the locks.

Twenty-six new, more powerful locomotives will increase the fleet from 82 to 1 units to keep up with the expected increases in transits after the cut is widene Running on tracks that sit atop the lock walls, the locomotives, measuring 26 m) long and 13 ft (4 m) high, provide about 10 percent of the ships' pulling an stopping power (the rest coming from the ships themselves). Their primary us however, lies in laterally positioning the ships to keep them from scraping the lock walls. Cables running from the locomotives to mooring posts on the ships are adjusted using hydraulic winches as the ship passes through the lock. At least four locomotives move with each ship, one on either side of the lock at t bow and one on either side at the stern.

More than 10 mi (16 km) of track, much of it dating from the original construct is being replaced at a cost of $125 million. Eighty-five years ago, the locomoti weighed only 40 tons (36 Mg). They now weigh 55 tons (50 Mg) and pull four times their weight. The increased loads have caused steel grillage under the r to deteriorate and move and have stressed the tracks and their concrete foundations.

The replacement project is a challenge because the teams work during the regular "lane outages" for lock maintenance, giving them just 10 days to completely replace 700 ft (213 m) of concrete base, tracks, and rails before ca operations resume. To save time, workers precut short sections of the track a concrete base with diamond chain saws. Pins are used to keep the segments place until the outage begins. Workers also preconstruct 40 ft (12 m) steel rai sections, each of which must be individually designed because of idiosyncras in the lock walls. The teams embed the new tracks in concrete treated with additives that cut down the drying time to five to seven days. Some of the installations, for example, sections that must incorporate a bridge over equipm in the lock wall underneath the tracks, use precast concrete foundations. The project began in 1996 and is scheduled for completion in 2003; it is 25 percen complete.

Some $20 million will be spent on a modernized vessel traffic management system that will use Global Positioning System technology to track ships in re time as they traverse the canal. New software will save man-hours on the ever-shifting scheduling of pilots-employees of the commission who steer ship through the canal-tugboats, and transit times. Such complex scheduling curre takes several hours a day.

Panama needs to find new sources of water to feed the canal because foreca show that ship transits and the demand for drinking water will increase sharpl the next 50 years. During the dry season caused by the 1997-98 El Niño phenomenon, water levels dropped so much in the canal's two reservoirs, Ga Lake and Lake Madden, that the commission had to impose draft restrictions ships. That meant vessels had to carry less cargo so they would sit higher in water. The drought showed that water supplies would probably be insufficient during a dry season to support the traffic increases expected after the rehabilitation and modernization program.

Recent market forecasts indicate that over the course of the next 50 years the number of canal transits could almost double. The amount of cargo moving through the waterway, currently more than 192 million tons (174 million Mg) annually, could quadruple in 50 years, requiring new, larger locks. But before locks can be considered, canal administrators must first find new sources of water or devise water-saving systems.

Current canal operations handle about 37 ships per day, with 34 lockages of water. A lockage is the amount of water needed to raise a ship from sea level the level of Gatun Lake, about 26 million gal (98,410 m3). Historically, the watershed has reliably provided water for only about 39 lockages a day; by 20 more than 55 to 60 lockages will be needed for all functions. Restrictions on s drafts during droughts could become more stringent and more frequent unless additional water supplies are found or comprehensive water management techniques are integrated into the operating system.

The need to find new sources of water has become more pressing with the rapidly increasing water demands from industry and municipalities, which currently use 220 million gal (832,700 m3) of canal water per day. At the pres time the canal watershed provides more than 95 percent of the potable water needed by cities adjacent to the canal. Potable water usage-equal to about fo lockages of water a day-is expected to double by 2020 and quadruple by 205 an equivalent of about 15 lockages a day.

Studies have looked at potential new dam locations on rivers to the west of th existing watershed. Since the rivers flow into the Atlantic and are outside the canal watershed, the water would have to be diverted to the canal through tunnels after the dams were built. Such dams could more than double the exis water supply, providing a basis for long-term capacity increases and accommodating the construction of new locks. They could also guarantee wa for municipal and industrial needs and prevent draft restrictions during drough New dams would produce hydroelectric power, which will be in demand to accommodate the country's population growth. Power sales could provide the revenue to pay for construction of the dams.

Feasibility studies on these options are just beginning. Because the potential sites are in remote locations with virtually no access, background information not available. No accurate ground surveys or geotechnical information exists which to accurately site and design the dams, and there are virtually no environmental or socioeconomic data. Much needs to be done before these d and their abundant water supplies can become a reality. But the promise of th supplies is enough to spur investigations into the types and sizes of new locks that could be built alongside the existing ones.

The Canal Capacity Projects Office is also looking at new locks and lift system that require less water to raise and lower ships. The existing infrastructure's reliability is being evaluated because many of the operating features of the loc date to the original construction, and after 85 years of service the locks are beginning to show some signs of wear. However, because the original design remain very functional and are difficult to change, many of the features, includ size and operating procedures, will remain unchanged after completion of the modernization program in 2005.

In support of long-term studies, planners are developing a detailed and comprehensive market forecast that will form the basis of future canal development. To be completed in about eight months, the forecast will include transit projections by ship type and size for the next 50 years, as well as the shipping routes for various commodities that will use the canal.

All of the parties involved in the rehabilitation and modernization program hop that enough water will be found to allow the new stewards of the canal, the Panamanian people, to enjoy the increased revenues and safety the program bring.

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[Related information on the Panama Canal]

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Title: Speeding toward China

Summary: Hong Kong's $20-billion program to build a new airport is racing toward the British colony's 1997 repatriation with China. The Hong Kong Airport Core Program is the world's most ambitious infrastructure project, a string of ten major transportation projects, almost any of which would stand out alone elsewhere.

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THE CONSTRUCTION WEEKLY
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Speeding toward China

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Hong Kong's $20-billion program to build a new airport is racing toward the British colony's 1997 repatriation with China. The Hong Kong Airport Core Program is the world's most ambitious infrastructure project, a string of ten major transportation projects, almost any of which would stand out alone elsewhere. Financed largely through the colony's sizable cash reserves, the projects are being managed and built on parallel fast tracks by a blue-chip roster of international contractors.

Shadowing the program is China, which last June finally signed off on final financial arrangements that preclude Beijing from assuming any debt after Hong Kong returns to Chinese rule. Like much that happens in Hong Kong, the program has been subject to international power politics between Britain and China, and internal review by a prickly local government.

``This is a big, complex and politically sensitive program," says James D.A. van Hoften, head of the New Airport Projects Coordination Office and senior vice president of International Bechtel Inc. NAPCO manages the overall project for the Hong Kong government, the Provisional Airport Authority, the Mass Transit Railway Corp. and a private venture, Western Harbour Tunnel Co. Ltd. Bechtel leads NAPCO's integrated management structure.

The go-ahead for the program came in 1989, pushed by increasing congestion at Kai Tak airport in densely populated Kowloon. When finished, passengers will travel from the new airport at **Chek Lap Kok** over 34 kilometers of new railway or highways to Hong Kong's central business district. Along the way, they will cross the two major bridges of the Lantau Fixed Crossing, and the 2-km immersed tube of the Western Harbour Crossing.

Financing is the dream of any government official. With fiscal reserves of $19.4 billion and exchange fund assets of $57.7 billion, ``Hong Kong can well afford this program," says one NAPCO official. Financing is supplied 75% by government equity and 25% by loans.

``We did not anticipate the strong growth of Hong Kong's fiscal reserves," notes Henry Townsend, executive director of the Provisional Airport Authority. ``It has put us in an extremely strong financial position." The PAA and MTRC, as autonomous government agencies with the authority to borrow, are putting up $4.7 billion and $3 billion, respectively. Each is borrowing $1.5 billion. Officials are publicly sticking to the scheduled completion date for the entire project, but privately believe it will take until spring 1998 to bring the job to a close. But by any measure, progress is remarkable. More than 150 contracts worth $11.8 billion have been awarded, most on a fixed-price, lump-sum basis. And most came in below estimates.

The first major contract, a $1.15-billion award to an international joint venture to build **Chek Lap Kok** Airport's 1,248-hectare site, is virtually complete. The contractor formed a 6-km-long island by leveling 302-hectare **Chek Lap Kok** island and a smaller neighbor to a height 6 m above sea level. Reclaimed land constitutes the remainder of the island. At peak, the contractor had most of the world's dredging fleet working to move over 400,000 cu m per day of fill, says Frans Uiterwijk, PAA site reclamation director. Some 347 million cu m of material were moved over the 41-month job.

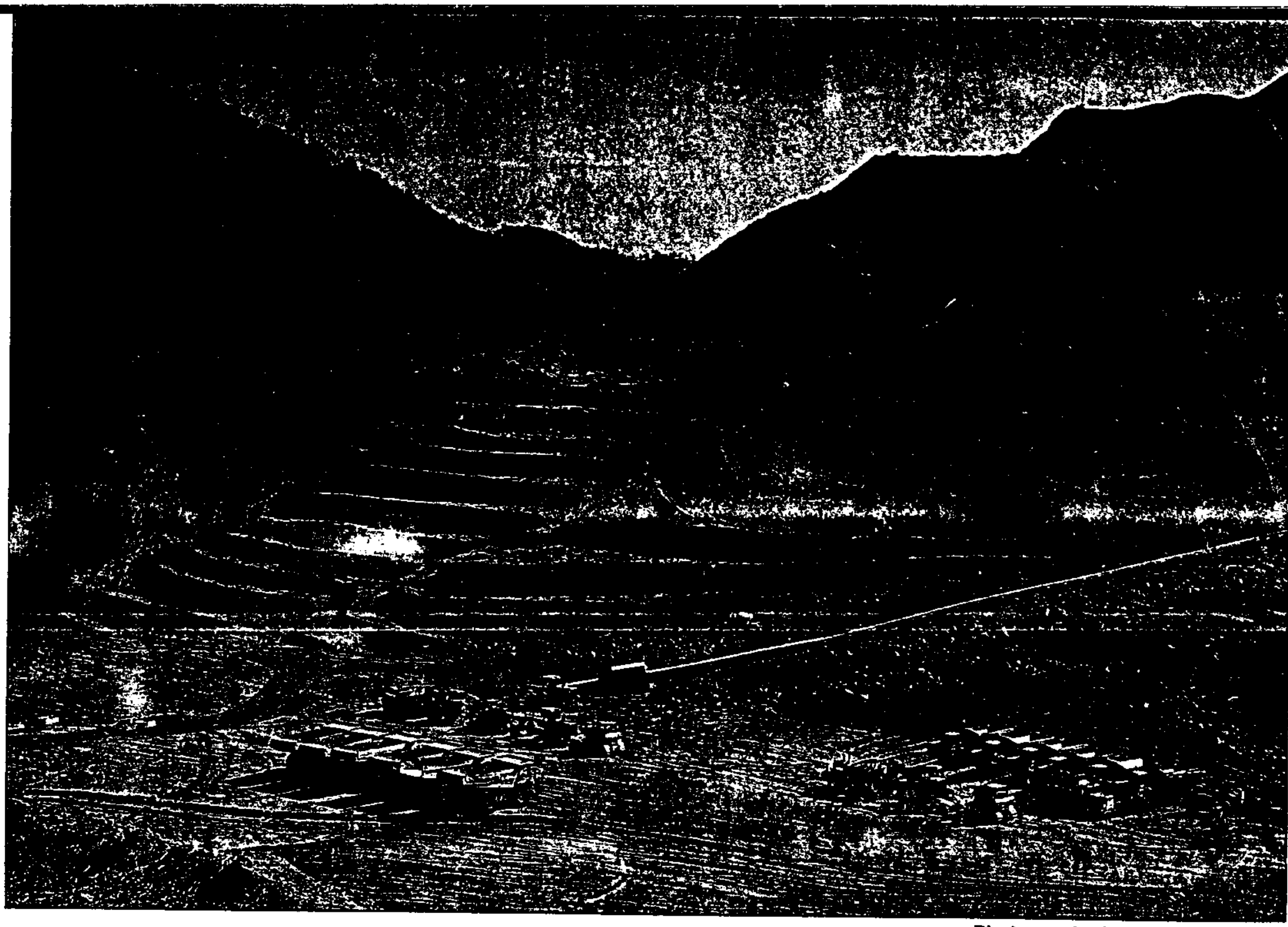
Foundations for the terminal began in May 1994 under a $60.4-million contract by Gammon Construction-Nishimatsu Joint Venture of Hong Kong and Japan. To prevent settling problems similar to those at Japan's Kansai airport, the terminal is being built on what was **Chek Lap Kok** island, not reclaimed land, says Alistair Thomson, PAA head of construction.

The terminal is being built by an international joint venture that includes China State Engineering Corp. and Kumagai Gumi (HK) Ltd. under a $1.29-billion contract. The 1.2-km-long terminal will cover a 490,000-sq-m area.

PAA supplied much of the earthmoving equipment for the island's formation to allow the contractor to begin work immediately. Thomson is doing the same thing for terminal and airport construction: concrete batch plants and other services are provided.

Logistics are the biggest problem so far. Because road links are not finished, all materials arrive by barge. And next year, more than 20,000 workers will be on site during peak construction.

``The important thing is getting this open on time," says Thomson.



Photography by Steven McBride

Conquering the MOUNTAIN

The success of North Carolina's most ambitious highway project to date—an expressway through the Appalachian Mountains—depends on managing tremendous quantities of excavated material in extraordinarily difficult terrain.

John Lansford, P.E.

The Interstate 26 project will be the largest and most expensive highway project ever undertaken in North Carolina. When completed in 2002, I-26 will provide motorists and commercial truck traffic safe and efficient interstate passage through the Appalachian Mountains between Johnson City, Tennessee, and Asheville, North Carolina. The highway will run 8.8 mi (14.2 km) through the steep, rugged terrain of Madison County, North Carolina, from U.S. Route 19 north to the Tennessee state line at Sam's Gap.

The project, which is expected to cost more than $200 million to complete, includes excavation of more than 35 million cu yd (26.8 million m^3) of material in cuts as deep as 600 ft (183 m), more than 100,000 linear ft (30,480 m) of drainage pipe, and 200 ft (61 m) tall embankment fills. Engineers must dispose of more than 8 million cu yd (6.1 million m^3) of waste material, avoid or cross numerous trout

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streams, provide access to the existing road network, and anticipate animal migration across the interstate.

The larger part of the route, dubbed A-10C, involves more than 25 million cu yd (19.1 million m³) of excavated material, approximately 79,000 linear ft (24,080 m) of drainage pipe, 470 ft (143 m) deep cuts through mountains, and 200 ft (61 m) high embankment fills. Gilbert Southern Corporation, of Atlanta, won the A-10C contract in 1996 with a bid of $105.6 million. The second part of the project, A-10D, involves more than 10 million cu yd (7.6 million m³) of excavation, more than 32,000 linear ft (9,750 m) of drainage pipe, cuts nearly 600 ft (183 m) deep, and embankment fills nearly 190 ft (58 m) high. A-10D was contracted in 1998 to Wright Brothers Construction, of Charleston, Tennessee, for $48.6 million. The success of the I-26 project will ultimately rest on the expertise of dozens of engineers in highway design, hydraulics, soils and foundations, geology, erosion control, structures, and construction.

Several challenges related to construction arose during the project design process, the most difficult of which was dealing with the huge volume of excavated material. The 25 million cu yd (19.1 million m³) of material to be removed from A-10C includes rock, earth, and unstable colluvium.

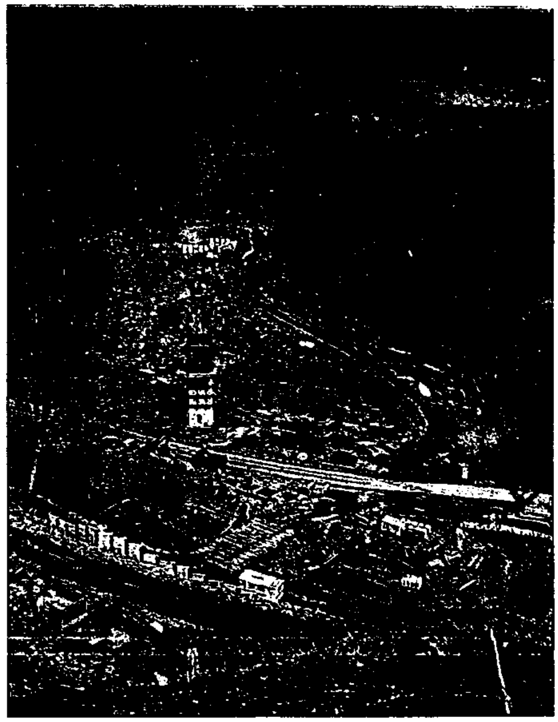
Though much of the excavated material will be reused in the high embankments, several million cubic yards of waste will remain. By widening the interstate design from four lanes to six—the additional lanes designed as auxiliary climbing and braking lanes for heavy trucks—engineers reduced the amount of waste.

To further reduce the enormous amount of excavation required on both projects, the North Carolina Department of Transportation (NCDOT) analyzed all 10 of the major cuts to see if steeper slopes could be substituted for the flat slopes used during the preliminary design. After an extensive geotechnical investigation that included more than 6,000 borings and 5,500 linear ft (1,676 m) of rock cores had produced additional information, the soils department of the NCDOT hired a noted rock slope expert—Duncan Wylie of Golder and Associates, Burnaby, British Columbia—to assist in calculating the maximum safe slope for each major cut.

Eventually the rock cuts were redesigned with steeper slopes to substantially reduce the total amount of excavation required, as well as the required right-of-way. The redesigned slopes rise as steeply as 6 in. (15.2 cm) for every linear foot (30.5 cm) and have 30 ft (9 m) wide benches at the top and bottom. For additional safety, 7,000 ft (2,100 m) of rock fence will prevent small rocks from reaching the traffic lanes. This fence will be located on the back of a combination concrete planter and wall that will contain vegetation to help conceal the fence from motorists.

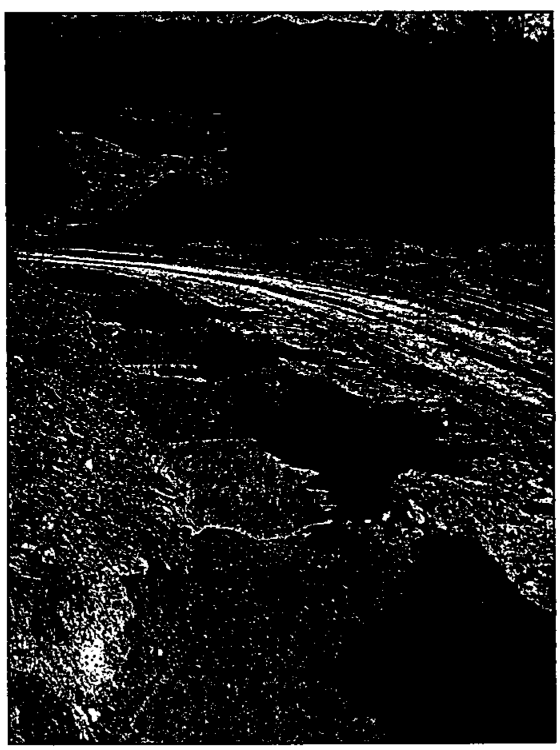
After all ideas for reducing excavated waste material had been exhausted, the NCDOT design still left 4 million cu yd (3.1 million m³) of waste material from both A-10C and A-10D.

The project isolated several valleys by eliminating public access to these locations. One valley is conveniently located in the middle of the A-10C excavation, where a welcome center for motorists entering North Carolina will be needed. The center will be built on top of more than 2 million cu yd (1.5 million m³) of material disposed of within this valley. Another valley, acquired on the north end of project, will contain the remaining A-10C waste, and two additional isolated valleys will store the A-10D waste. All waste areas for

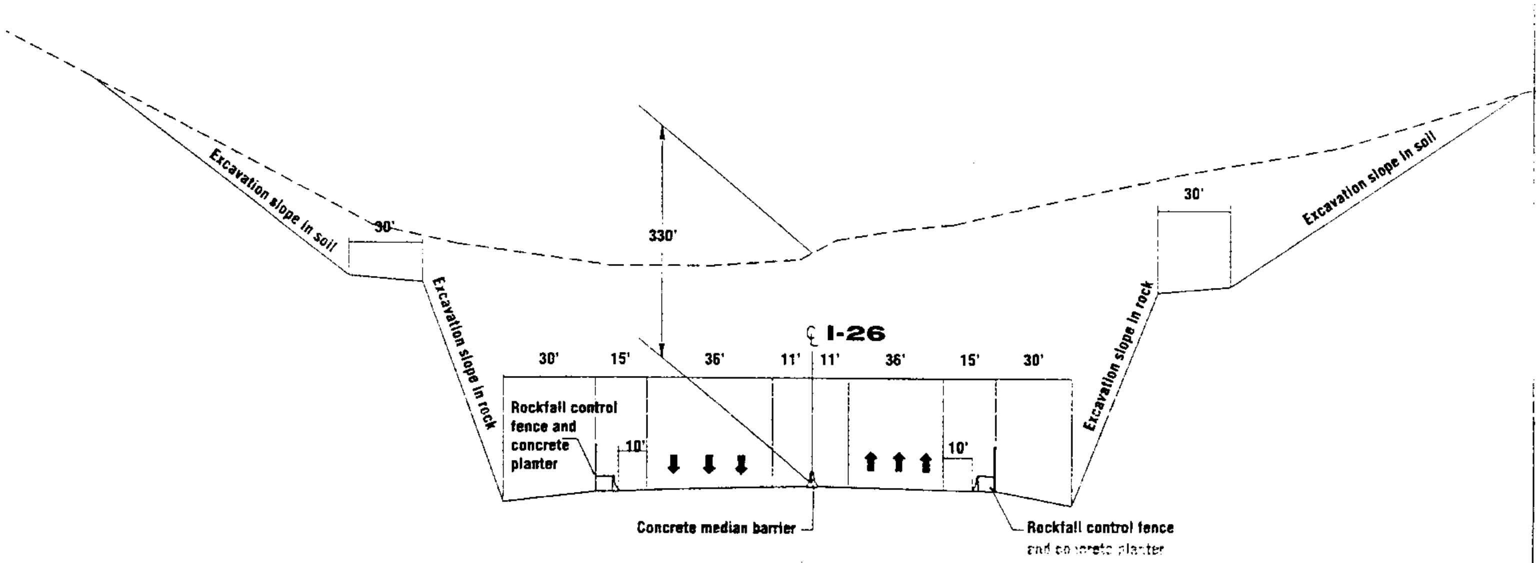


BENCH CUTS *in the hillside* opposite *will help stabilize the fill that will be added later. The 800 ft (244 m) long Laurel Bridge, shown under construction* above, *towers 220 ft (67 m) above a secondary road.*

A SERIES *of rock-check dams,* below, *provide erosion control for a drainage area above the road. Silt will be removed from the drainage ditches on a regular basis.*



Typical Section of I-26 Passing through Buckner Gap



both projects will be graded, seeded, and planted with natural vegetation to restore the habitat as soon as possible.

Some of the waste removal presented unusual problems. Colluvium, which is essentially old landslide debris that has slowly accumulated on the long slopes of the mountains, is often very wet, has numerous springs flowing through it, and contains large boulders and a great deal of organic material. Building an interstate over such deposits is not acceptable; the material would slide under the weight of the embankment, causing constant failures and expensive repair operations. The NCDOT's soils department recommended that all of the colluvium, which ranged in depth from 10 to 50 ft (3 to 15 m) and amounted to more than 3.5 million cu yd (2.7 million m^3), be removed.

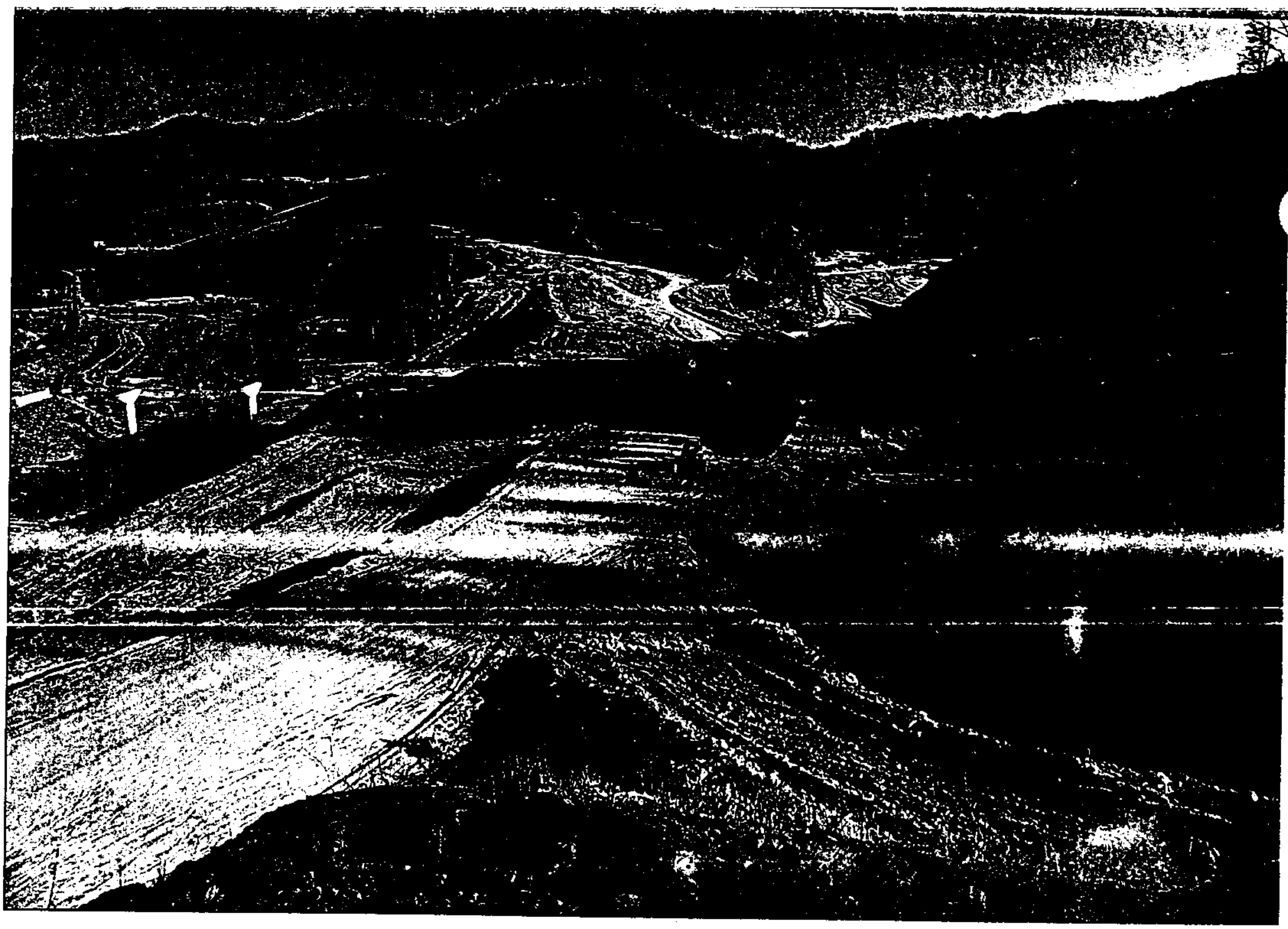
But even total removal of the colluvium was not always enough to ensure stability for the high embankments. In some locations large rock buttresses rather than a traditional earth embankment will support the interstate. Made of rock blasted from the cuts along the project and in some locations more than 150 ft (46 m) high, the buttresses will be covered by 3 ft (0.9 m) of earth where feasible to encourage the growth of vegetation and conceal the stone.

Madison County, where the project is located, contains some of the most rugged mountains in North Carolina, with elevations ranging from 2,220 ft (671 m) at the south end near U.S. Route 19 to 4,000 ft (1,219 m) at Sam's Gap. Because of this wilderness environment, there were many wildlife issues. Numerous streams wend through the mountains, and nearly all those affected by the I-26 project are designated as trout streams—critical waterways requiring special attention. Some, such as Laurel Creek and Little Laurel Creek, had to be avoided by the construction entirely to preserve their pristine water quality. All of these issues were well documented in the environmental impact statement for the project.

After negotiations with numerous wildlife agencies, the NCDOT agreed to pay for the restoration and reconstruction of some 26,000 linear ft (7,925 m) of trout streams in Madison County. This reconstruction, led by Raleigh-based North Carolina Water Resources, the state water agency, will involve rebuilding the stream banks, adding vegetation, creating separate cattle-watering facilities, and fencing off the streams to keep cattle from damaging the banks. It will also include adding such "trout-friendly" details as pools and root wads, which are created when the root balls of small felled trees are left in a stream to act as breakwaters. To assist in stream mitigation, about 1,500 ft (457 m) of Little Laurel Creek's headwaters will be reconstructed, including rebuilding the stream banks, removing existing pipes, and adding meanders and pools to the streams.

Though every effort was made to minimize the harm to streams, some streams had to be filled in or relocated, and many ended up flowing through pipes or culverts. The hydraulics unit designed several culverts up to 2,000 ft (610 m) long, with ledges and natural streambed material in their bottoms to provide sufficient water flow for trout migration. The unit also used modern stream reconstruction techniques to move about 400 ft (122 m) of two streams with the assistance of experts from water resource agencies. These streams, which have now been rerouted, have meanders, pools, ripples, and overhanging vegetation to keep them cool during the summer months.

It was not just trout that project designers had to work around. The design also had to include two crossings for large animals because the new road will affect the habitat and migration patterns of black bears. Each crossing is essentially an 8 by 8 ft (2.4 by 2.4 m) concrete culvert placed in a remote area along the project in the hope that bears and other large animals will cross under the interstate rather than braving the



ENGINEERS RELOCATED *Route 23 to fit the Bear Branch interchange.* above, *around the local route and nearby Laurel Creek.*

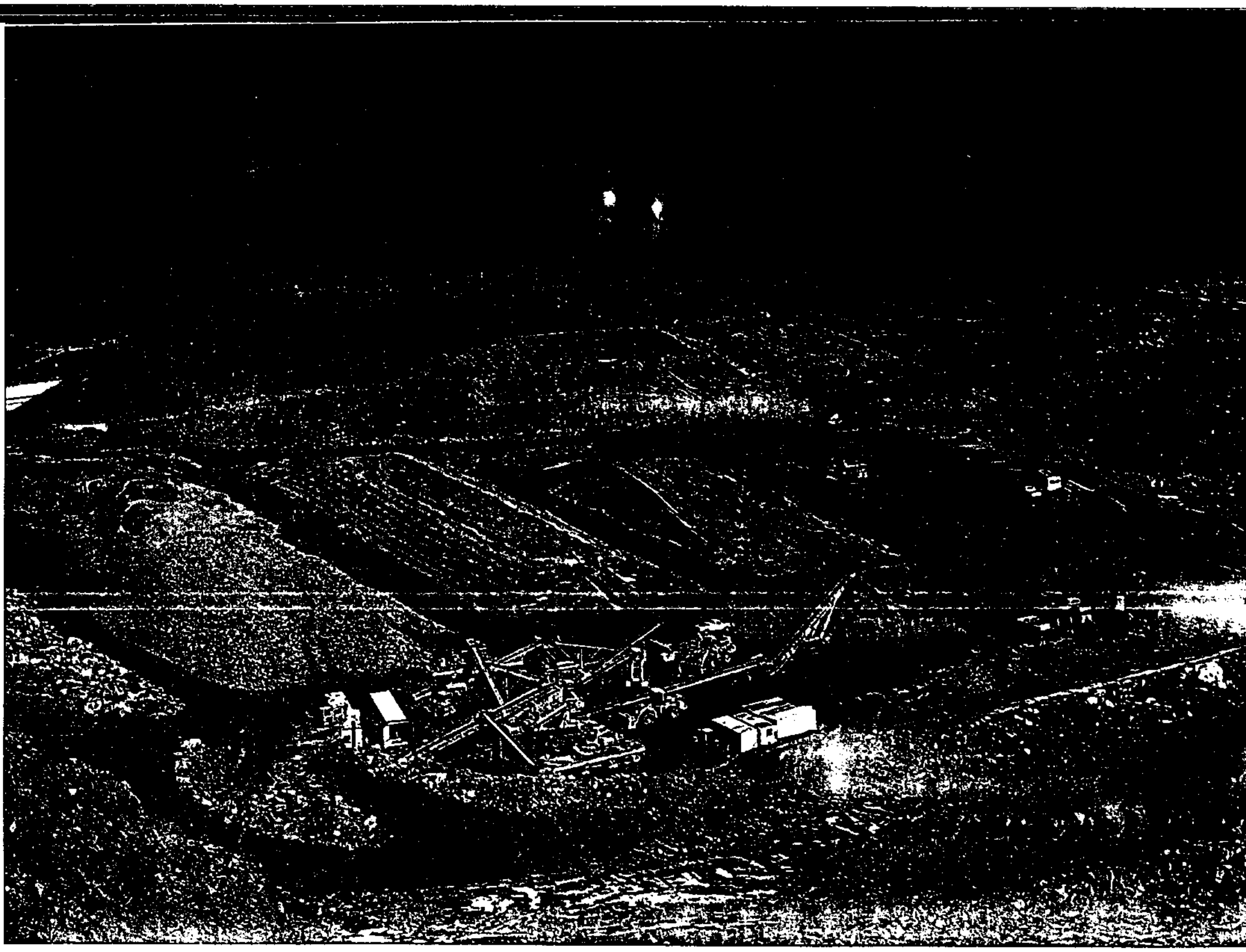
traffic lanes. Fencing attached to the culverts will funnel animals toward the crossings, and vegetation around the crossings will provide cover. This method, requested by the U.S. Fish and Wildlife Service and the North Carolina Wildlife Resources Commission, based in Raleigh, has been used in the western United States but has not yet been tested in North Carolina.

Passageways for wildlife have been successfully used in Europe, particularly in the Netherlands, where they have been developed as an outgrowth of national ecological policies. There are essentially five types of passageways in use there: canals, which are designed for small mammals and amphibians; stump walls, for small mammals and insects; amphibian tunnels, for toads and other small amphibians; "ecopipes," for small mammals; and "ecoducts," for large mammals. The design and construction of ecoducts involve targeting specific species so that appropriate dimensions are incorporated; using straight, linear forms so that the animals can see from one end of the passage to the other; and including fencing that guides the animals into the passages.

Because of the steep and difficult terrain and the numerous streams and waterways running through the project location, providing sufficient room for erosion control measures was vitally important. Therefore, a large amount of right-of-way was included at the bottom of fills within the project limits. The NCDOT's roadside design unit incorporated large sediment basins, silt dams and fences, brush barriers, and permanent rock dams into the project plans and placed strict limits on clearing operations. Buffer zones consisting of 25 ft (7.6 m) of vegetation between the construction and existing streams provide both filtration for runoff and shelter for the fish. Velocity suppression pools at the outlet end of every drainage pipe slow the water flow, providing a settling basin for sediment and preventing downstream erosion. A program for monitoring water quality, contracted out to a private consultant, continues in the streams surrounding the construction, with measurements of turbidity as well as levels of acid, heavy metals, and silt.

Emergency spill retention basins at each truck escape ramp and at the truck inspection station at Sam's Gap will prevent toxic fluids from reaching the streams. Instead of pouring directly into natural streams, surface runoff from the interstate will collect in extensive drainage systems and empty into grass-lined ditches. This system will filter out pollutants before the runoff reaches the streams.

Geologic investigation showed that some samples contained sulfidic rock. When exposed to water, this type of rock breaks down and creates a weak sulfuric acid. If the acid reached natural streams, it would have a devastating effect on aquatic life. If large quantities of sulfidic rock are found during



THE NORTH *Carolina Department of Transportation purchased an additional right-of-way to store crushed stone that will be used in erosion control and as a road base. Appoximately 500,000 tons (453,597 Mg) of stone will be used.*

excavation, the acid will be neutralized in enclosures of thick plastic and waterproof clay. The enclosures will be buried well above the water table and surrounded by additional layers of lime and crushed limestone, which can neutralize the acid.

As the design of these projects progressed, plans were distributed to several contractors with experience in moving huge amounts of excavated material. The contractors made several suggestions that were incorporated into the project to make it more feasible, such as providing contour maps of the area and detailed summaries of slopes, rock cut locations, and erosion control devices.

Providing access to the local road system was a balancing act between cost and potentially harmful environmental effects. The only suitable location for an interchange required near the community of Laurel, in northern Madison County, was in a very narrow valley bordered by Laurel Creek on one side and steep mountainous terrain on the other. U.S. Route 23 ran close by on the opposite side of Laurel Creek, and Bear Branch Road—a rural secondary route serving several homes—crossed the project in this valley.

A standard diamond interchange design could not be used to connect the highway to Bear Branch Road because squeezing all four ramps, the interstate, and the secondary road into the valley would affect Route 23 and Laurel Creek. The solution was to move Route 23 200 ft (61 m) away from the interchange, thus keeping the design of Bear Branch Road within acceptable guidelines while avoiding the trout stream. To work around the environmental constraints, the entire interchange had such close design tolerances that adjusting any of the eight alignments required adjustments to all of them.

Grade separations were needed to maintain public access to three other roads located at the southern end of the project. To save money, two of these roads were relocated along a 1 mi (1.6 km) stretch and connected to Higgins Branch Road at a point where a grade separation was already planned. This decision eliminated the need for two extra bridges (one of which would have been more than 100 ft [30 m] high) and provided the needed access while reducing the overall construction cost.

The biggest bridge on the project is situated at a crossing of both Laurel Creek and Laurel Creek Road about 2 mi (3.2 km) from the Tennessee state line. This bridge is nearly 800 ft (244 m) long and more than 220 ft (67 m) above the secondary road. The bridge design contractor, URS Greiner of Raleigh, North Carolina, presented alternatives ranging from traditional three- and five-span structures to two types of arch bridges. After review, a five-span bridge with tapering columns was selected

HARD ROCK *slopes were split on a smooth plane by explosive charges set into holes drilled in the rock. More than 8 million cu yd (6.1 million m³) of waste material will be generated by the project.*

and, to meet future needs, was designed to carry six lanes of traffic.

Perhaps the most unusual intersection that faced I-26 planners was the juncture of the newly cut highway and the historic Appalachian Trail. The highway will cross the trail at the Tennessee border, where the trail already intersects Route 23. Some form of safe and aesthetically pleasing crossing had to be provided for the trail, and a grade separation had already been designed to allow I-26 to pass over Route 23. After discussions with the U.S. Forest Service, which has jurisdiction over the Appalachian Trail, the NCDOT decided to relocate a portion of the trail so that it passed under the interstate at the Route 23 grade separation. The new design will also provide a small parking lot off Route 23 for trail users.

The challenges did not end once contracts for the I-26 project were awarded in 1996 and 1998. The weather has become a factor, especially during the winter months. The contractors can get little accomplished between December and March, when heavy and persistent rain or snow makes it impossible to operate equipment. Heavy rains caused a landslide during the winter of 1997–98 that required the removal of an additional 500,000 cu yd (382,400 m³) of material from A-10C and the construction of a new rock buttress to support the remaining slope. The specifications governing the erosion control devices have been increased dramatically over the original estimates to contain the sediment from the incredible amount of rainfall in the winter of 1997–98. During the summer and fall of 1998, however, so little rain fell that the contractors had to use over 100,000 gal (378,500 L) of water each day to keep down the dust. The drought did benefit the contractors in one way, however: the colluvium was often so dry that it could be reused in the embankments rather than being removed to a waste site.

By 2001 the I-26 project will have involved the removal of more than 35 million cu yd (26.8 million m³) of material over nearly 9 mi (14.5 km) of future interstate at a cost of more than $150 million. The new interstate is expected to open in 2002. When it does, North Carolina and Tennessee will have a newer and better route through the Appalachian Mountains, one that will provide safe and efficient travel between the two states for decades to come. ▼

John Lansford, P.E., is a project design engineer at the North Carolina Department of Transportation in Raleigh, North Carolina.

Project Credits

Contractors: Gilbert Southern Corporation, Atlanta, and Wright Brothers Construction, Charleston, Tennessee.

The Unofficial

I-26 Construction Madison County North Carolina

Pages

This website is the unofficial location for the I-26 corridor under construction in Madison County, NC. It includes a vicinity map, photographs and information on the projects currently under construction between US 19 and the Tennessee State Line. An update is included as well detailing the latest construcion on the projects.

PROJECT A-10C

Project A-10C begins at the US 19/US 23 intersection north of Mars Hill, and runs north to Laurel Creek Road, a distance of 5.968 miles. It has been described as "the largest single construction project in the history of NCDOT", and was awarded in October 1996 to contractor Gilbert Southern for the amount of $105.6 million. This project traverses some of the most rugged terrain in North Carolina ever crossed by a major highway. Elevations range from approximately 2500' at US 19 to over 3500' near Buckner Gap, with numerous streams and tributaries needing to be crossed or diverted. Many of them are designated as trout streams, requiring extensive care in preventing silt from entering the undisturbed portions of these waterways. The existing slopes are very steep once the project crosses Jarvis Creek Road (about 1 mile north of US 19) and remain so until the northern end of the project near Laurel Creek Road. Many areas along the project have unstable soil conditions, requiring the removal of this material before actual construction of the highway can begin.

This project will involve the construction of the main highway, its drainage and any bridges needed along the route. Secondary roads needing relocation will be constructed in their entirety as well. The paving, guardrail, signing and median barrier will be added on another project once the grading is completed. Six lanes are being graded on the current project, and three will be paved on the uphill grades on a later project. On the downhill grades a wide paved shoulder will be constructed for the use of trucks if they need it. The entire corridor is designed to a 60mph criteria, and much of A-10C will be built on a 6% grade (about 5 miles of it in fact). An interchange is planned at Bear Branch Road, and a site for a Welcome Center for traffic entering North Carolina is going to be built as well. A scenic overlook will be constructed at the Welcome Center, and a separate overlook built for the northbound traffic.

To help protect trucks from endangering the public, this project will include two truck

Some statistics to show the sheer size of this project:

Unclassified excavation	23,400,000 cubic yards estimated to be removed
Undercut material to be removed	2,400,000 cubic yards
For visual purposes, a million cubic yards will fit into a cube 300' on a side. This project will move over 25 of those cubes!	
Fill heights range up to 200' high from the existing ground	
Cut depths range down to over 350' deep from existing ground	
Over 84,000 linear feet of drainage pipe will be used on this project, with over 11,000 linear feet of 60" structural steel pipe alone. The order for drainage pipe on this project was the largest single order for pipe ever recorded in the United States, according to the pipe supplier.	

Four culverts are planned on A-10C. One is on Higgins Branch, another is on Jarvis Creek, and two are on Bear Branch Creek. There are four bridges; two at the Higgins Branch grade separation, one on Bear Branch Road, and one on I-26 crossing over Bear Branch Road. An animal crossing is to be built between Jarvis Road and Buckner Gap to allow large mammals such as bears a safe route under the highway.

Two waste areas are included on the project to help the contractor avoid needless environmental damage created by having to dispose of over six million cubic yards of waste material. One of these sites will support the future Welcome Center; the other will be reseeded and encouraged to return to a natural state.

PROJECT A-10D

The second portion of the I-26 corridor, A-10D, was let to contract in January 1998 to Wright Brothers Construction for $48,550,000. This project runs from the north end of A-10C at Laurel Creek to the Tennessee State Line at Sams' Gap. The project is 2.832 miles long and traverses several ridges and fills on the way up to the TN State Line. Elevations along the construction range from 2880' near Laurel Creek to over 4000' at Sams' Gap. The cuts and fills are among the highest on either project, with a 600' deep cut and 200' high fills. A 220' high bridge over Laurel Creek is included in this contract, in addition to a grade separation at Sams' Gap where US 23 will pass under the new Interstate. The Appalachian Trail will also pass under the Interstate at this location.

Some more specific measurements on this project:

Unclassified excavation	8,850,000 cubic yards of material estimated
Rock Excavation	5,166,000 cubic yards estimated
Waste material	4,160,000 cubic yards estimated
Undercut material	1,165,500 cubic yards estimated
6600' of 60"structural plate pipe, to be placed under the large fills on the project and over six miles of drainage pipe overall.	

The highway is designed to 60mph speed, with a 22' median and barrier and six lanes to be graded. When the paving contract is let, three lanes will be constructed on the uphill side and a wide paved shoulder built beside the usual two lanes on the downhill side. One truck escape ramp will be constructed, as well as an inspection station near the Tennessee State Line for truckers to get information about the highway between there and US 19.

There are two large waste areas designated to dispose of the waste excavation. One is a large valley that has been isolated due to the rugged terrain and the highway location. It had been strip-logged previously and was purchased by NCDOT. The other one was a smaller valley isolated in the same manner as the first area. Both areas will be reseeded and returned to a natural condition when construction is completed.

GEOLOGY

These projects had very intensive geologic investigations conducted during the design phase. A geophysical survey was conducted in 1990, and geologic field mapping was begun in 1992. Over 6000 individual rock structure measurements were made over the 10 miles of area surveyed. Oriented rock core borings and soil overburden analysis was begun in 1993; over 5500' of oriented coring was conducted, analyzed and stored for the contractor to use during construction.

Most of the soil in the area was determined to be either colluvium or residual materials. Some of this material was over 50' deep. Soil deposits were underlain by saprolite or weathered rock in most cases. The residuum materials were red to brown medium-stiff to stiff sandy and silty clay. Maximum thickness was about 12'. The saprolite was more dominant, and was up to 10' deep in some places.

The colluvium made up the remainder of the soil material. Colluvium is ancient landslide material, and was made up of wet, silty material mixed with rocks ranging from six inches across to over 30' across. Use of this material in the highway construction is difficult; in order to use any of this material the rocks have to be separated and the remainder of it mixed with residual or saprolite. It is also very wet and exhibited good (too good!) water retaining abilities. A foot thick layer of colluvium often did not dry out even when left out in the September sun for a week. Most of this material has been disposed of in the waste sites along the project, although some is being carefully used in the actual construction.

The rock type is a Precambrian metamorphic rock of the Blue Ridge Belt, made up of biotite-granite gneiss. The borings found some instances of acid producing rock (i.e. sulfides). These rocks, if placed in areas where water could seep through them, have the potential to form weak sulfuric acid, which would be lethal to the trout streams in the region. To prevent this in the event this rock is found in significant quantities, cells will be designed with layers of crushed limestone, clay, agricultural lime and thick plastic liners around the acid rock to isolate it from the rest of the environment.

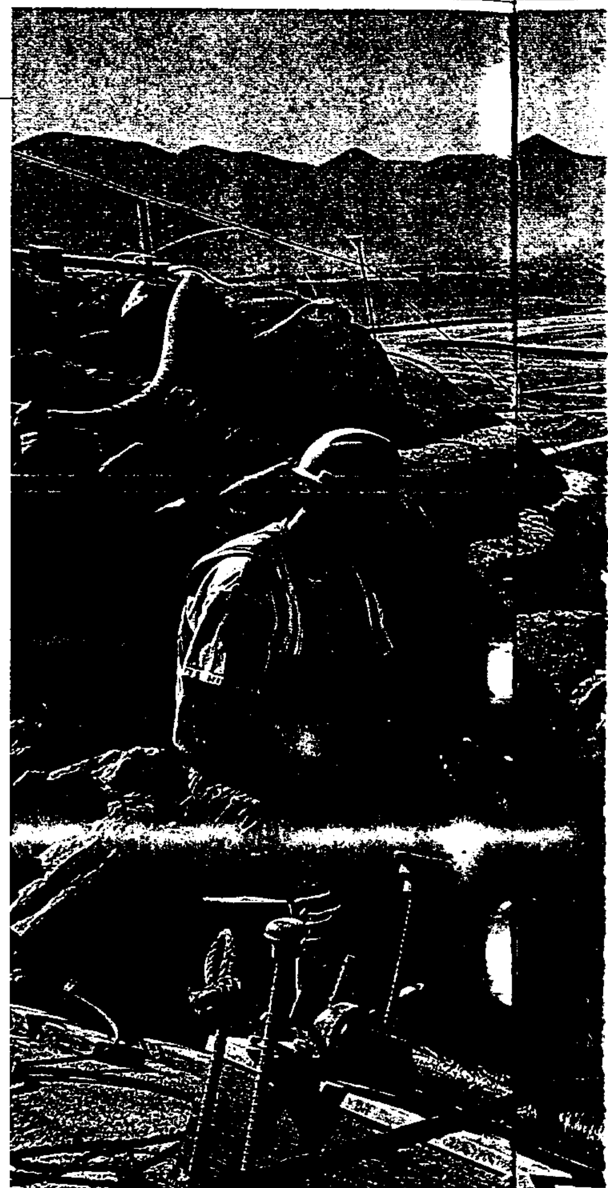
The photos I've placed on the webpage include several views of the construction along the length of the projects showing various interesting items. As work continues I will add more pictures to those already here so that viewers can see how the site changes. Photographs for project A-10D are included as well.

Anyway, hope you enjoy this website. If you have any questions, please email me.

COVER STORY EARTHMOVING

Dust, Dirt Test Crews

Reservoir to help supply water to region in case of earthquake



WALLING IN A DRY VALLEY From grouting gallery at north abutment, West Dam will stretch 1.7 miles. **STORING WATER IMPORTS** Majors, at reservoir's future pumping plant, drives entire $1.9-billion project.

Cornered behind plexiglass, a mastodon skull smirks at indignant neighbors. But the Ice Age fossil, found at the nation's largest earthmoving job, is largely disregarded. Meeting in the visitor center of the Eastside Reservoir Project, these neighbors meet to complain about the job's sometimes 20-hour-a-day schedule. Crews nearby go about excavating and backfilling 250,000 cu yd per day—one of the highest rates ever in the U.S.

The $1.9-billion job resembles a mining operation in scale and cost. A 6-ft-tall person standing beside one of the 195-ton end-dump trucks just reaches the bumper. Gargantuan 12-ft-dia tires on the 22.2-cu-yd rubber-tired front-end loaders cost $45,000 each; tire chains, $30,000 each.

The residents from Hemet, 90 miles southeast of Los Angeles, meet to complain about hearing "the roar of the engines all night long." And they moan about the dust: "I can hardly breathe," says one. The tone of the meeting differs markedly from regional and national forums where the project's owner, the Los Angeles-based Metropolitan Water District of Southern California, usually gets praised for mitigating the social and environmental impacts.

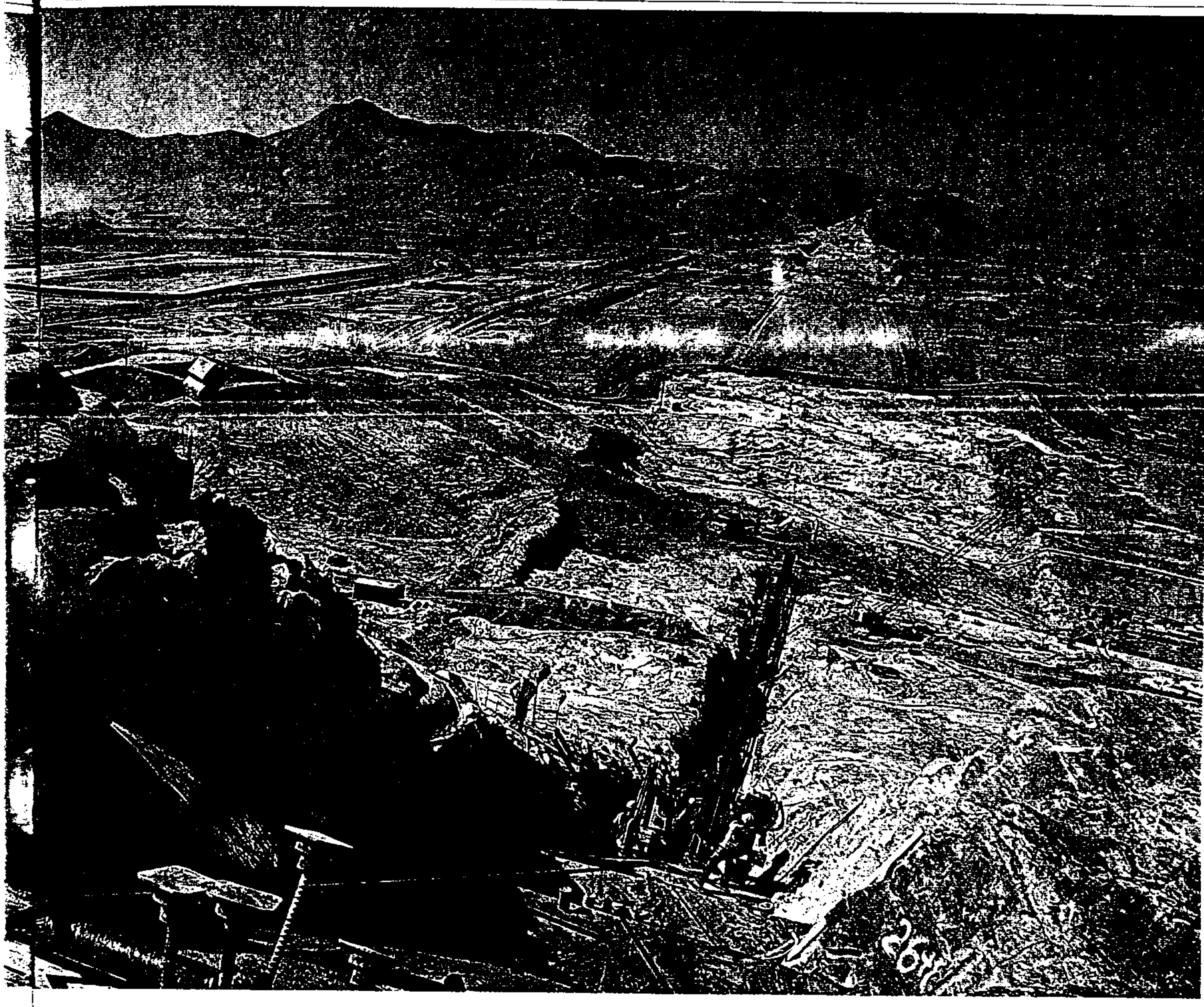
The district supplies more than half the water used by 16 million Southern Californians. MWD imports water from northern California and the Colorado River and to be ready in case the aqueducts rupture in an earthquake, it plans to increase its surface-storage capacity. Its new Eastside Reservoir will nearly double its supply to six months. The resulting 800,000-acre-ft lake, the region's largest, will cover 7.5 square miles, at an elevation high enough for gravity-flow to reach most customers.

The 4,500-acre site extends between two rows of hills, in a dry valley nearly two miles across and 4½ miles long. The West Dam will be 285 ft high with a 1,800-ft-wide base, extend 1.7 miles between the hills and contain 65 million cu yd of material. Dams elsewhere contain more. But this job stacks up considerably with the inclusion of the Saddle and East dams. One will fill a saddle in the northern hills and contain a mere 2.6 million cu yd. The East Dam will hold 45 million cu yd and measure 2.1 miles long, 180 ft high and 1,200 ft wide at the base.

VISIBLE At the present schedule, the three dams will start becoming visible above grade next year. Each will contain a core of nearly impervious alluvium, compacted firmly. Filters on either side consisting of unweathered rock crushed into sand will trap any core material that tries to pipe away. Outside the filters, drains consisting of gravel-sized rock will permit any water from the core and filters to drain away. Outermost layers will consist of a transition zone of minus 6-in. diameter rock, plus a shell of rock with a maximum diameter of 30 in. to hold the inner layers in place. For seismic reasons, exteriors will slope at a ratio of one vertical to two horizontal, with cores about double the typical width in such dams (ENR 8/12/96 p. 28).

Today at the West Dam, bottom-dump trucks go about placing earth for filters and drains in 12 and 18-in.-high lifts, compacted with 10-ton vibratory rollers. End-dump trucks, each 150-ton capacity, place the rock shells in 3-ft lifts, before rollers move in. For all three dams, the construction involves excavating more than 150 million cu yd, and placing 110 million cu yd in the dams (with the rest in new, adjacent recreation areas).

The excavations take place almost entirely within the valley to minimize disruptions to neighbors, some of whom live within 1,000 ft of the grading operations. Work goes on day and night, partly to minimize the period of disruption. Some of the crews work double shifts, to



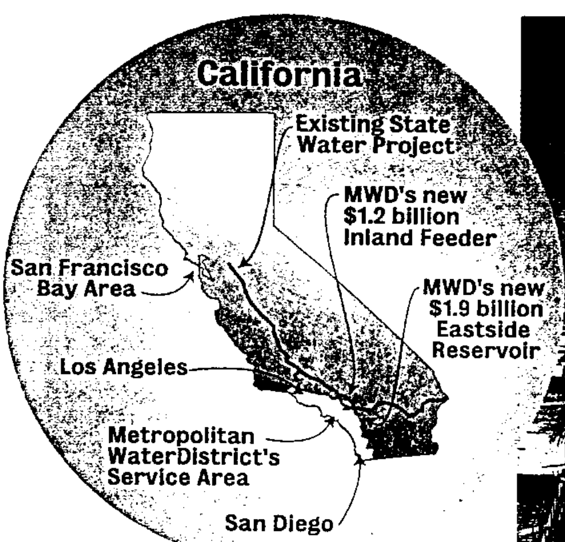
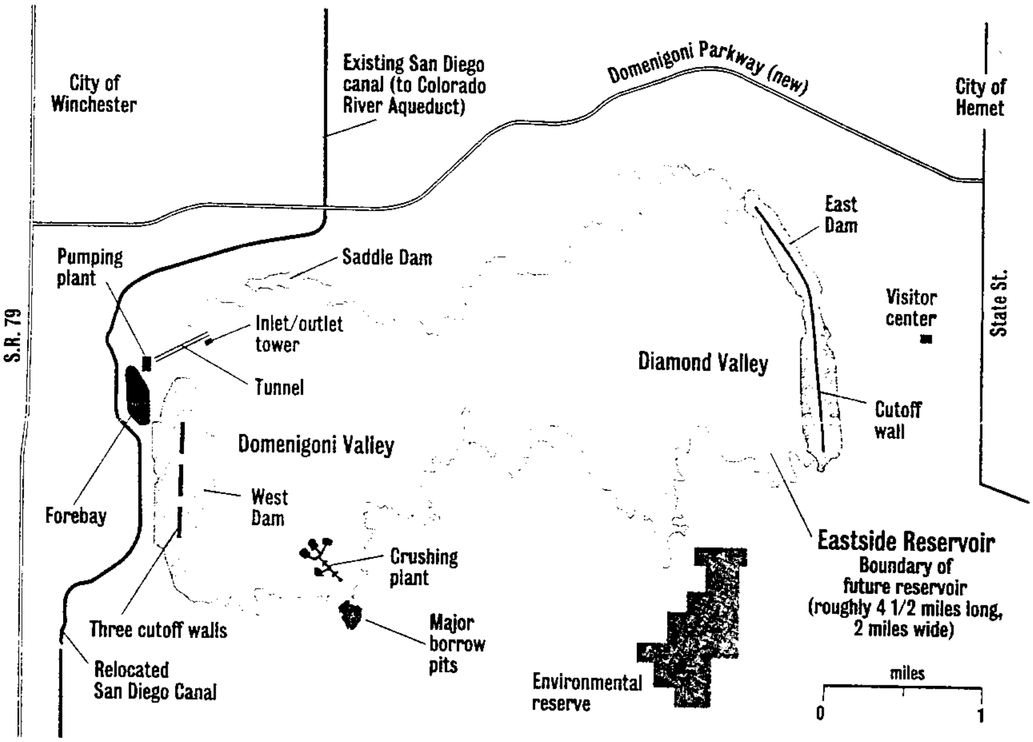


ILLUSTRATION BY CHRISTOPHER J. WEIR FOR ENR; PHOTOS BY MICHAEL GOODMAN FOR ENR



BIG VALLEY Southern California's largest reservoir will cover 7.5 square miles (left).

BIG DRINK Rendering depicts West Dam and reservoir after 1999.

BIG DIG Nation's largest earthmoving job involves excavating 150 million cu yd or more (right, top).

BIG TRUCKS On cabs of mining-sized 150-ton-capacity trucks, green and red lights signal when to keep shoveling in.

maximize returns on one of the largest components of the project's cost: the leasing of heavy equipment. If the crews all worked a mere 40 hours per week, "It increases the cost of the job about 35%," says MWD Project Manager Dennis G. Majors. That would push the completion date from 1999 into 2006.

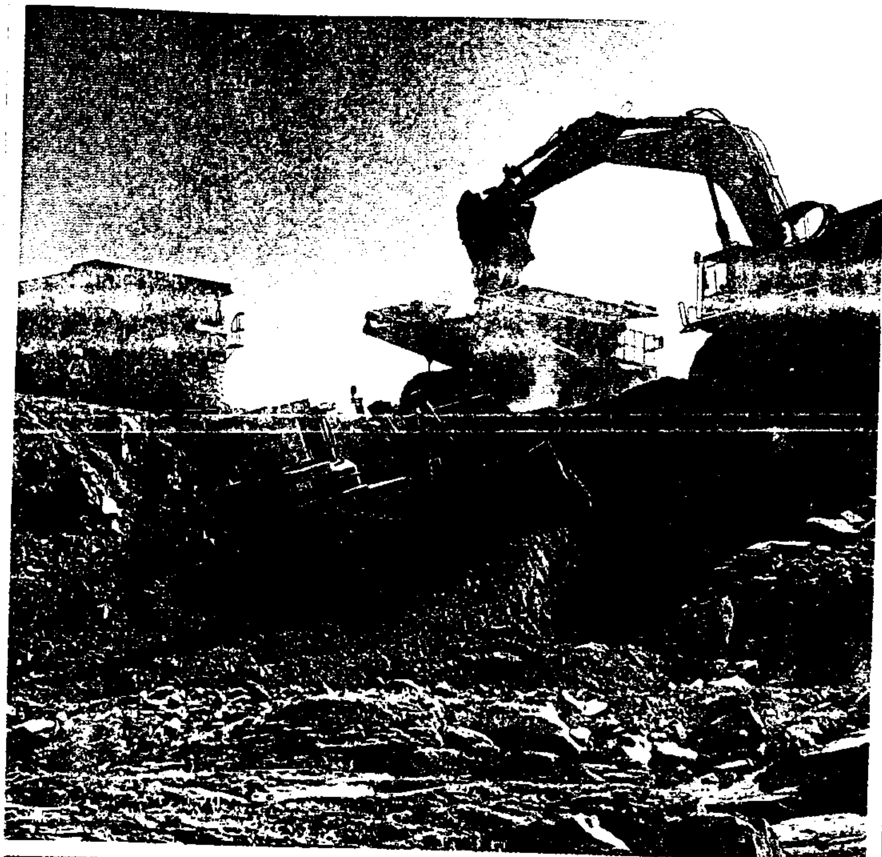
Sometimes the project gains and loses publicity points at about the same time, as on June 27 when crews found more mastodon bones at the East Dam site, the day after East Dam neighbors met to complain of dust and noise. The paleontological digs hardly disrupt construction (ENR 8/26/96 p. 13).

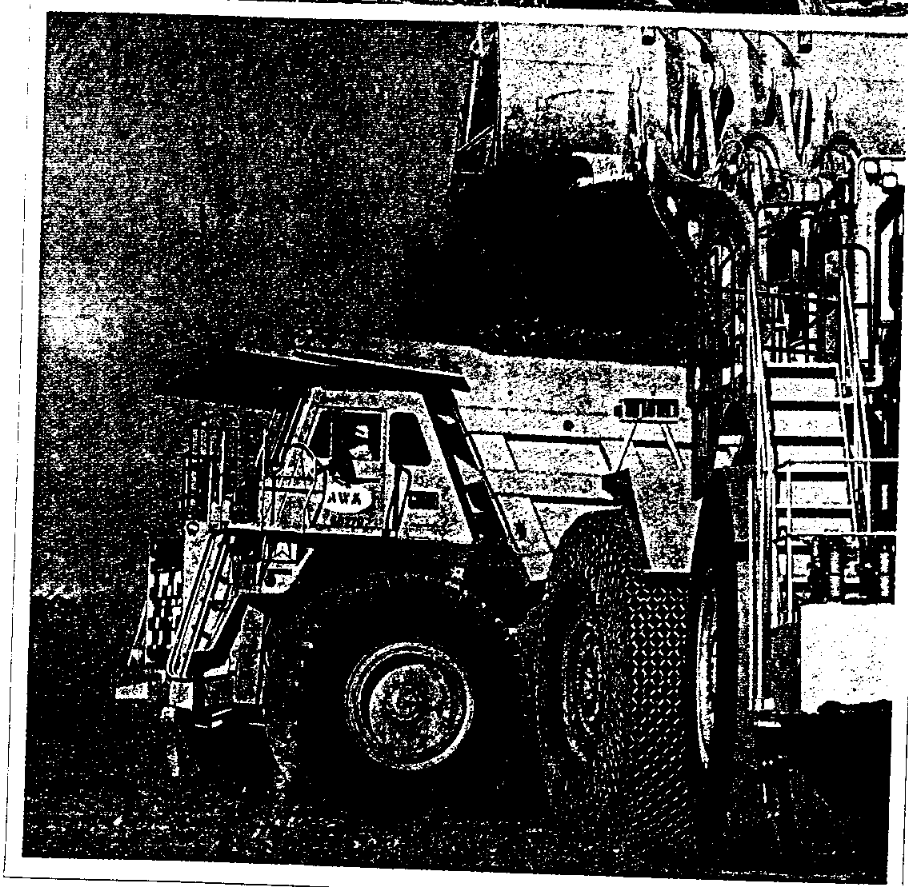
Observers are astonished at the accelerated pace from conception to construction. Planning began just 10 years ago. The environmental review, accelerated under Majors' leadership, finished up in 1993. MWD took a proactive approach to mitigate for sensitive species by purchasing 12,700 acres for two nature reserves. In exchange, regulators agreed not to block the project after construction began.

After starting the screening studies in 1988, New York City-based Raytheon Infrastructure Services Inc. (formerly Ebasco Services Inc.) performed the design from 1993 to 1996. Its bill now totals $68 million, including ongoing post-design services. The construction costs now average $1 million per day, with the total for construction alone expected to reach $1.4 billion. The job is huge even by the standards of MWD, which previously performed its own construction management. For CM services from 1995-1999, the district is paying $49.5 million to a 55/45 joint venture of Parsons Corp., Pasadena, Calif., and Chicago-based Harza Engineering Co.

Construction began in 1995 but really took off in 1996 after the award of MWD's single largest contract ever. The $384-million, 42-month contract—now at about $400 million with anticipated change orders—went to a 45/35/20 joint venture of Atkinson Construction Co., San Bruno, Calif., Washington Construction Co., Missoula, Mont., and HB Zachry Co., San Antonio. The team also won two related contracts. Its $40-million contract involves building a 271-ft-high inlet-outlet tower; and a 13-million contract includes a 2,226-ft-long tunnel from the tower to the pumping plant.

The Atkinson team, now about a third done at the West and Saddle dams, works two 10-hour shifts on weekdays plus two 8-hour shifts on Saturdays. Unlike smaller dams, work at the West Dam proceeds simultaneously on excavation, grouting, construction of cut-off walls and embankment. Staging the work simultaneously "probably cuts nine months off the job," says Robert L. Portley, the





team's project manager. Meanwhile, the team applies 2.5 million gal of water per day to control dust.

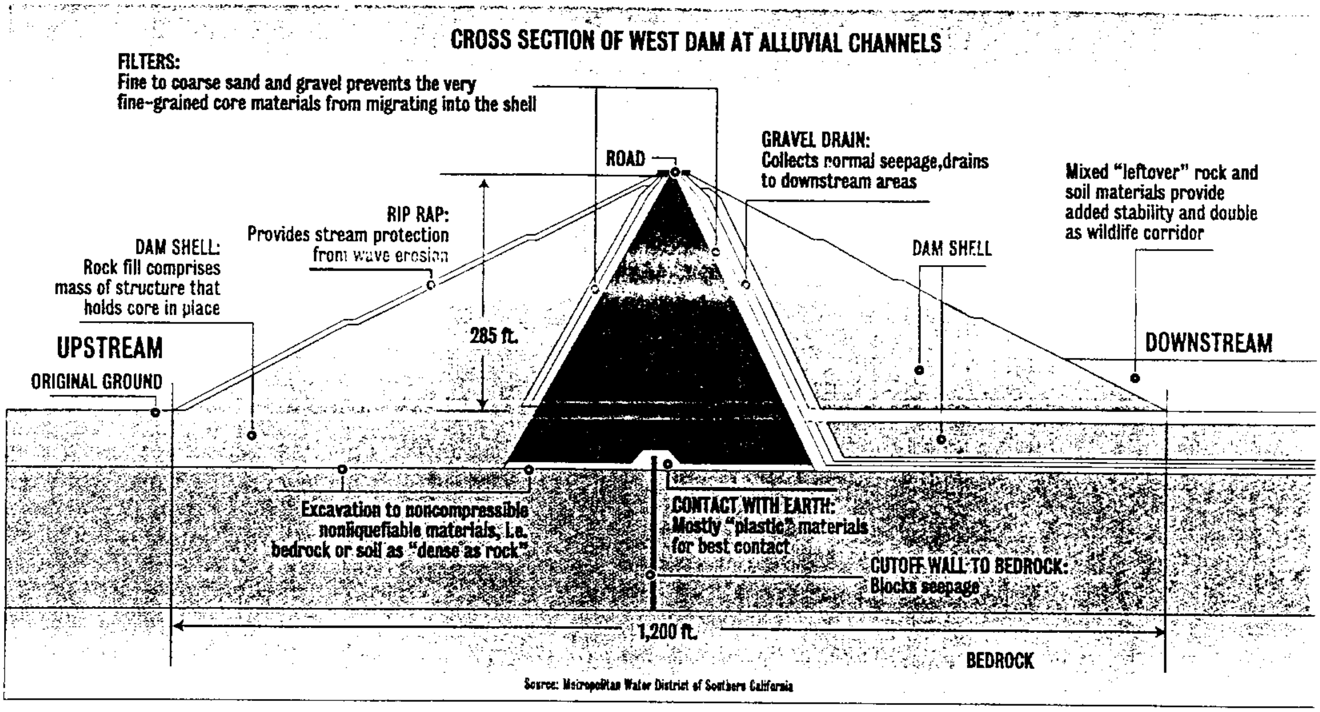
Local regulators still fret about the dust, in particular at one of the largest crushing plants ever on a construction site (see cover). The Atkinson team's fully computerized, $15-million plant stretches over a half mile with two side-by-side crusher lines. The goal: crush 24 million tons in 24 months, starting from last October. Per MWD's orders, Atkinson's team must provide the East Dam team team some of that—10 million tons crushed to 6-in.-minus—because Atkinson's team works the be[illegible] quartzite quarry. Including that material for the East Dam, the plant can kick out 3,200 tons per hour of sand filters, concrete aggregate, road base and 6-in.-minus.

CRUSHING Unlike most crushers with three separate stages, this one contains four. From borrow areas about half a mile away, 30-in.-minus material gets broken down into 8 to 12-in.-diameters in the primary stage, 6-in.-minus in the secondary, 2-in.-minus in the tertiary and ¼-in.-dia sand in the impact stage. Water for sand washing—20,000 gpm—comes from dewatering at the West Dam and the San Diego Canal.

The plant's output includes extraordinarily clean filters. But some crumbles more than anticipated during handling, transporting and compacting. Although filters must be clean enough to permit any water from the core to pass through, MWD agreed at the request of the Atkinson team to permit up to 5% of the filter material to pass a No. 100 sieve, not the specified 2%. "It really wasn't much of a change—and what that did was accommodate the operation of the contractor," says Joseph L. Ehasz, originally project design director at Raytheon, now on loan as MWD's area construction manager for dams.

Designers are making other modifications, too, because of two problems at the quarries. No one expected to find so much so-called stripping rock—the weathered layer above unweathered, hard rock. Nor did anyone foresee such a large transition zone of "dirty" rock between stripping rock and hard rock. Before construction began, MWD spent $12 million investigating foundation conditions and quarries with 4-in.-dia borings. "You can never do enough investigations to cover all the situations you find in actual construction," says Assistant Construction Manager Brian A. Anthony, a Harza vice president.

Stripping rock can be bulldozed and ripped, but hard rock must be drilled



SEISMIC DESIGN
Self-healing design protects impervious alluvial core (top).

LEAD DESIGNER
Ehasz directed dams' design, but now helps keep 22.2-cu-yd front-end loaders, with 12-ft-dia tires and chains, on track.

DESIGN CHANGES
Anthony figured out how to use both stripping rock (brown) and unweathered rock (purple).

ILLUSTRATION BY ANTHONY A. LAND FOR ENR; PHOTOS BY MICHAEL GOODMAN FOR ENR

and shot. Originally, engineers called for using stripping rock outside of the West Dam's core, on the upstream side below grade. When bidding the project, Atkinson's team expected to remove 8.65 million cu yd of stripping rock, but now expects to find 11 million. About 2 million cu yd have been stripped so far. Revised plans—with impacts on the Atkinson team still being negotiated—call for using some of the excess on a berm downstream of the West Dam and on the dam's downstream shell and perhaps in the new recreation areas, although that involves longer haul distances. The negotiations seem under control, thanks to partnering.

MWD is handling the problem of too much "dirty" rock, always intended for the rock shells but containing more sand than anticipated. Originally, engineers wanted no more than 20% of rock-fill passing a No. 4 sieve, but are testing whether to permit 30%, depending on how much the material settles under vibratory rolling. "It's well within the standards of dam construction," says Ehasz.

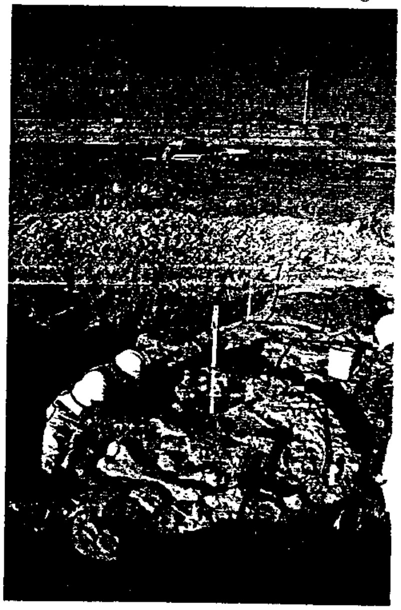
The overall design reflects lessons learned at Idaho's Teton Dam (ENR 2/16/78 p. 34). There, inadequate grouting contributed to failure. At the Eastside Reservoir, unweathered rock beneath the dams exhibits so few fractures that MWD focuses mostly on keeping expensive water from leaking out, says Jack L. Tyler, MWD's resident grouting engineer. With so few fractures, each bore hole in the grout curtain typically takes just 7.5 lb of cement. The entire program—one of the largest ever—involves percussion drilling of 791,500 linear ft of holes 2½ in. in diameter, as deep as 200 ft within rock.

At the West Dam, one of the largest grouting subcontracts anywhere went to Pittsburgh-based Nicholson Construction and its Italian parent Rodio Inc., for $29 million. At the East Dam, grouting gets under way in earnest this month by subcontractor Sudhakar Engineering, Wyomissing, Pa.

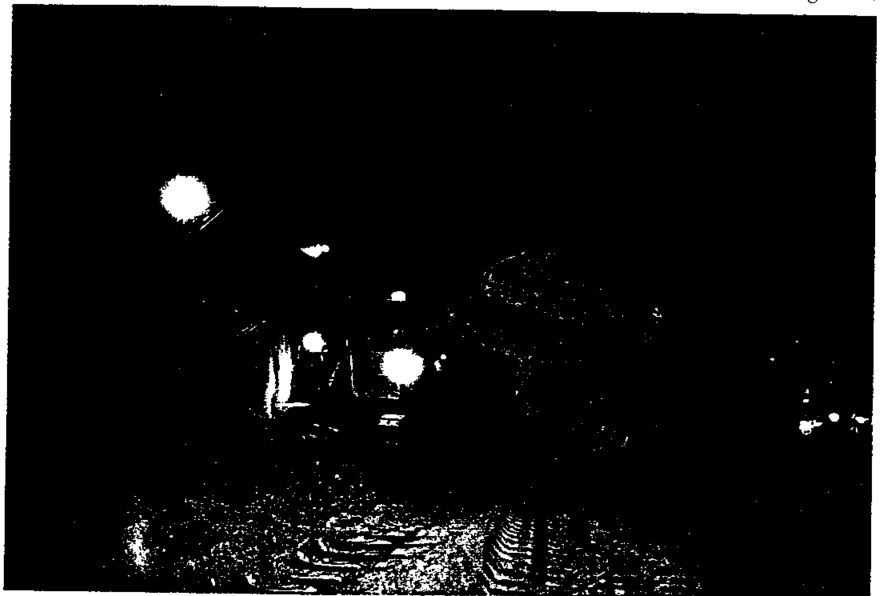
The general contract for the East Dam work belongs to a 70/30 joint venture of Kiewit Pacific Co., Vancouver, Wash., and Granite Construction Co., Watsonville, Calif. It is about one-fifth done with work on the 32-month contract after receiving the notice to proceed last December. Its crews work two nine-hour shifts, five days per week. The team declines to discuss its activities.

But the Atkinson and Kiewit teams keep tabs on each other. After all, they competed for each other's work. Both lost out to Advanco Constructors, Upland, Calif., which won a $62-million contract to build the pumping plant. Going solo, Kiewit ended up with initial foundation work at the West Dam for $20.5 million (ENR 3/13/95 p. 20). In subsequent bidding to build the West and Saddle dams, Kiewit's team lost to Atkinson's by $11 million (ENR 11/27/95 p. 9). But Kiewit's team beat Atkinson's by $25 million to build the East Dam for $275.5 million (ENR 9/9/96 p. 10).

Atkinson's team attributes its loss of the East Dam contract partly to a lack of equipment. To haul material for the West Dam's core, Atkinson needed all its 16 bottom belly dumps from the 1980s. Unlike the single-belly, 75-cu-yd dumps used by Atkinson, which cost at least $250,000 each to replace, Kiewit's team uses 140-cu-yd double-bellies. The larger size carries more material for the same labor cost, but takes longer to load, costs more to buy and gets less gas mileage. Neither team's equipment choices seem superior, says Rodney J. Somerday, an MWD resident construction engineer: "It's what you're used to working with, really."



MASTODON FOSSILS
Crews turn up Ice Age bones, such as these on June 27 at East Dam.



BEASTS OF BURDEN
Mammoth equipment now rules the valley working up to 20 hours a day.

By winning the East Dam contract, Kiewit's team took on the difficult task of building a cutoff wall, 9,000 ft long, beneath the core. The core goes as deep as 110 ft below grade but still sits mostly on inferior weathered rock. So a 30-in.-thick concrete wall must descend through that weathered rock as deep as 100 ft, to socket into better rock below.

In contrast, the West Dam's core goes 80 ft below grade but sits pretty much on unweathered rock, with three exceptions. The core sits on alluvium in three ancient channels up to 180 ft deep and 1,500 ft across. There, the Atkinson team's 3-ft-thick concrete cutoff walls must go as deep as 120 ft through alluvium—just into rock.

For the East Dam wall, Kiewit's team must drill 30-in.-dia holes close together, deep through weathered rock. MWD sees the team struggling to fine-tune the use of rotary augers and down-hole percussion hammers, and questions the early mobilization efforts of joint-venture subcontractor Kajima Engineering and Construction Inc., Pasadena, Calif., and SMW Seiko Inc., Oakland, Calif. "They're bringing in more gear and more people," responds David V. Imper, the Kiewit team's project manager.

The overall project involves huge equipment. Kiewit's chose 195-ton mining trucks. Atkinson's picked 150-ton trucks, after considering acquisition costs, production economics, projected resale values and anticipated shipping costs to subsequent jobs. In a $50-million-plus lease-purchase deal, Atkinson's team acquired about 45 major pieces of rolling stock including two 22.2-cu-yd front shovels, a 13.7-cu-yd front shovel, a 13.7-cu-yd backhoe/front shovel, twelve 150-ton trucks, eight 95-ton trucks, three 14-cu-yd rubber-tired loaders, a backhoe and sixteen tractors.

Most came with "vital information management systems" that began hitting the street a few years ago, although rarely used in general construction even now and never before by Atkinson. Among other things, the systems monitor payloads. Atkinson keeps its productivity-versus-plan numbers confidential, but Portley says, "It's pretty well in line with what we anticipated."

The information systems also pinpoint problems with engine functions, and complement the Atkinson team's $500,000 maintenance facility and 60 mechanics. Furthermore, the systems' sophisticated electronics substitute for mechanical governors to control horsepower, emissions and fuel consumption.

Fuel consumption by the Atkinson team averages 625,000 gal per month. Expecting to pay 70¢ per gal, the team decided against purchasing several million gallons in bulk. Prices rose to $1 last summer before settling back to 80¢. "In retrospect, I probably would have gone and locked it in," says Mike Monnot, the team's equipment superintendent.

Another choice raised eyebrows, too. The Atkinson team looked at the benefits of washing and reusing engine filters up to three times, versus replacing them for $100 to $200 each when dirty the first time. Considering the dusty conditions, the team decided against reuse, "which is kind of a controversial issue," Monnot says. "On the surface, it looks like we made the correct decision," he adds pointing to just a few engine failures so far. The engines cost more than $70,000 to replace. But with filters kept clean, they typically run up to 16,000 hours before needing an overhaul. Atkinson's team runs its equipment 20 hours a day on weekdays, and 16 hours on Saturdays. ❑

By David B. Rosenbaum in Hemet

PHOTOS BY MICHAEL GOODMAN FOR ENR

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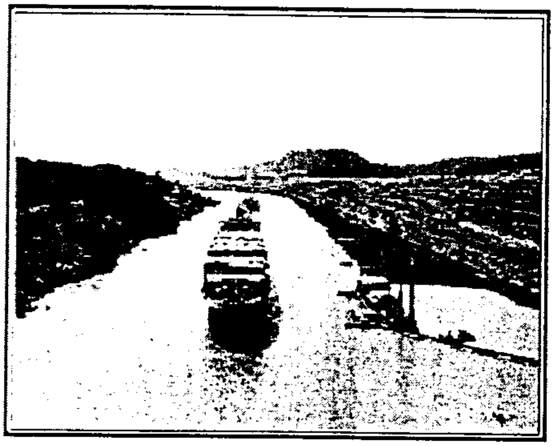
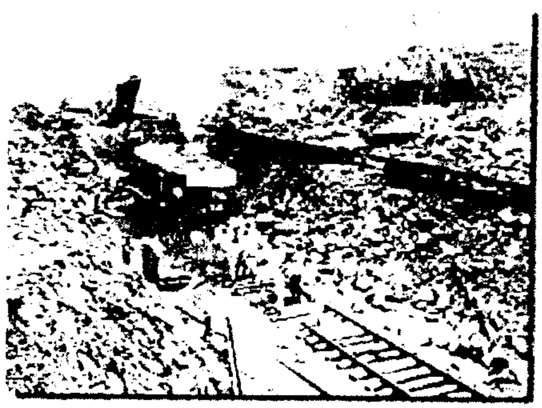
Gaillard Cut Widening Program



The Gaillard Cut Widening Program consists of widening the Cut from its existing 500 feet to a minimum of 630 feet along straight stretches and 730 feet at curves. The program was initiated to meet growing shipping demands by increasing the waterway's sustainable operating capacity and allowing greater flexibility in transit scheduling by permitting two-way traffic of wide-beam vessels in the Cut.

What is Gaillard Cut?

Because of its history, its unusual geology and the fact that it slices through the Continental Divide, the Panama Canal's Gaillard Cut holds special interest for the general public, especially for crew and passengers on board transiting vessels. Called Culebra Cut during the Panama Canal construction period, it was later renamed for Col. David du Bose Gaillard, the engineer in charge of this section of Canal construction work.



This portion of the channel is about 8½ miles (12.6 kilometers) long and was carved through rock and shale for most of the distance. It was here that the principal Canal excavation took place and here that major slides occurred during construction soon after the Canal was opened and several times thereafter.

On August 15, 1914, the world hailed the opening of the Panama Canal, the monumental engineering achievement of the century. This event marked fulfillment of the centuries-old dream of uniting the world's two greatest oceans and forging a new link in the world transportation chain.

The building of the Panama Canal was an unprecedented triumph and the product of almost superhuman endeavor, with at least 75,000 men and women contributing to the work during the 10-year construction period. Canal builders created Gatun Dam, the largest earth dam ever built at that time; Gatun Locks, the largest concrete structure ever erected at that time; and Gatun Lake, the largest artificial lake at that time. It also created the Canal watershed, the healthiest strip of tropical terrain anywhere in the world, and a water link across 50 miles (80 kilometers) that were, in the words of author David McCullough, "among the hardest ever won by human effort and ingenuity." The hardest-won stretch of all was Gaillard Cut.

A ship traveling from the Atlantic to the Pacific enters Gaillard Cut where the Chagres River flows into the Canal channel at Gamboa. More than any other section of the Canal, the Cut gives the distinct impression of being an enormous ditch. Today's observer must bear in mind that the excavation goes down some 48 feet (14.6 meters) below the surface of the water. A short distance before a southbound ship reaches Pedro Miguel Locks, it passes Gold Hill on the left, the highest promontory along the channel. The hill rises 539 feet (164 meters) above sea level, but is currently being reduced because of Cut widening activity.

Contractor's Hill, on the west bank of the Canal opposite Gold Hill, originally had an altitude of 410 feet (123 meters), but was reduced to 370 feet (111 meters) in 1954 to stabilize the hill. The hill is being further reduced to 95 feet under the widening. During the 1930s and 1940s, the straight section immediately north of Gold Hill was widened from its original 300 feet (91.5 meters) to 500 feet (152 meters) to provide a passing section for large ships, and during the period from 1957 to 1971, the remaining portions of the Cut were also widened to 500 feet (152 meters).

Trend Toward Larger Vessels

Over the past few decades, average ship size began a moderate upward trend. It is now expected that the number of PANAMAX vessels (the largest that will fit in the Canal locks) transiting the Canal will increase from about one-fourth of total oceangoing transits to over one-third of transits by the year 2010. For example, transits by PANAMAX vessels with beams of 100 feet (30.5 meters) and over increased to more than 29 percent of total oceangoing transits in FY 1997.

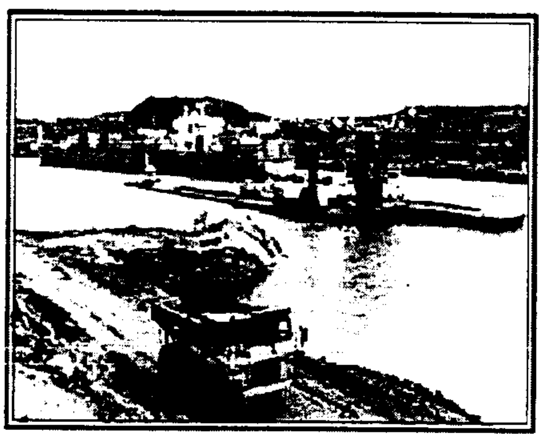
Because of Gaillard Cut's narrow width and sharp turns, large vessels cannot meet and pass safely in this section of the Canal. As more large ships transit the waterway, traffic congestion and delays are more likely, thus affecting the Canal's ability to provide expeditious transit service in the next century.

Although the Canal now has adequate capacity to handle current and projected levels of traffic, the Panama Canal Commission is intent on ensuring that the Canal will continue to have sufficient capacity and reserve margin to provide high quality transit service and to efficiently handle unforeseen traffic surges well into the next century. The Panama Canal Commission has always had high service standards and it measures its performance against an internally developed, self-imposed benchmark standard of average Canal waters time (CWT) of 24 hours for transiting vessels. To uphold this standard and thus continue to meet the challenge of global changes in shipping, Canal management closely monitors trends in ship size and other key parameters to assure a margin of sufficient reserve capacity to allow an average CWT of 24 hours.

Feasibility Studies

In 1982, the Panama Canal initiated feasibility studies that included hydrodynamic modeling in Sweden and the design of a new channel layout using computer simulation, which was primarily carried out by the Computer Aided Operations Research Facility (CAORF) of the U.S. Dept. of Transportation at King's Point, New York. Following further analysis of construction methodologies, operational conditions, cost estimates, financing alternatives and environmental assessments, the studies recommended the widening of Gaillard Cut over a 20-year period by contracting all of the dry excavation above water level and using in-house resources for all the wet drilling, blasting and dredging needed to complete the $200 million (in 1991 dollars) project.

Cut-widening Program Approved



In July 1991, a long-range program to widen the Cut was approved. The work is described as a major effort to take the Panama Canal, as its builders originally conceived it, to its maximum capacity. The proposal was to carry out the task with internal resources and mostly within the Canal's operating budget, as much as possible.

The first dry excavation contract was awarded in December 1991, with work beginning in January 1992. Engineers estimate that 29.2 million cubic yards (22.3 million cubic meters) of material will be removed under 18 separate contracts.

The agency's Dredging Division was placed in charge of the wet excavation phase, initiated in January 1994. With the help of a new, land-based rotary drill rig, the current drillboat Thor, and the 15 cubic yard (11.5 cubic meter) dipper dredge Rialto M. Christensen, dredging personnel began to remove an estimated 14.9 million cubic yards (11.4 million cubic meters) of underwater material. The overall estimated total is 44.1 million cubic yards (33.7 million cubic meters).

In 1996, because of recent increases in Canal traffic, especially in wide-beam vessel transits, the Panama Canal Commission re-evaluated the timetable for program completion. The new construction timetable will have the Gaillard Cut widening completed in 2002, ten years ahead of the original schedule. The plan involved purchasing additional dredging support equipment in fiscal year 1996 and 1997; augmenting further the Commission's drilling and blasting capabilities; and increased the single-dredge operation with a two-dredge operation in fiscal year 1998. New equipment included a land-based hydraulic excavator with support from four 50-ton-class off-road trucks; these arrived in late August 1997.

The total estimated cost of the widening program is $218.7 million.

Benefits to the Shipping Industry

The widening is part of a broader, currently ongoing $1 billion modernization and capacity improvement program. In addition to increasing Canal capacity, it will also benefit the waterway by improving the quality of transit service following locks outages and reducing the risk of landslides that could disrupt Canal operations. Also, many of the existing restrictions, including those limiting traffic flow to a single direction, can be eliminated, increasing locks utilization potential by more than 90 percent.

By actively working to provide for two-way safe passage of virtually all vessels 24 hours a day, together with modernization and improvement programs to enhance Canal capacity, efficiency and safety, the Panama Canal aims to ensure that the waterway will remain an essential part of the Panamanian economy and a viable artery for world trade well into the next century.

Program Status (October 1999)

- The dry excavation is 91 percent complete which represents 21.0 million bank cubic meters out of 23.0 million bank cubic meters of the total dry excavation. Tie-Up Station is the only remaining dry excavation project.

- Two-dredge operation program, Dipper Dredge Rialto M. Christensen and Cutter Suction Dredge Mindi, and the land excavator Liebherr, continue the wet excavation. The overall wet excavation is 60.0 percent complete and totals 6.9 million bank cubic meters.

- Subaqueous drill and blasting is 88.5 percent complete. Land drilling and blasting is 78 percent complete. Overall drilling and blasting operations are 83.25 percent complete.

- Two Panamax vessels, the largest able to pass through the Canal locks, were able to meet at Bas Obispo Reach last May, as part of the testing being conducted by Canal officials and the US-based Waterway Simulation Technology Inc. The consultants will be submitting a report indicating the results of the testing.