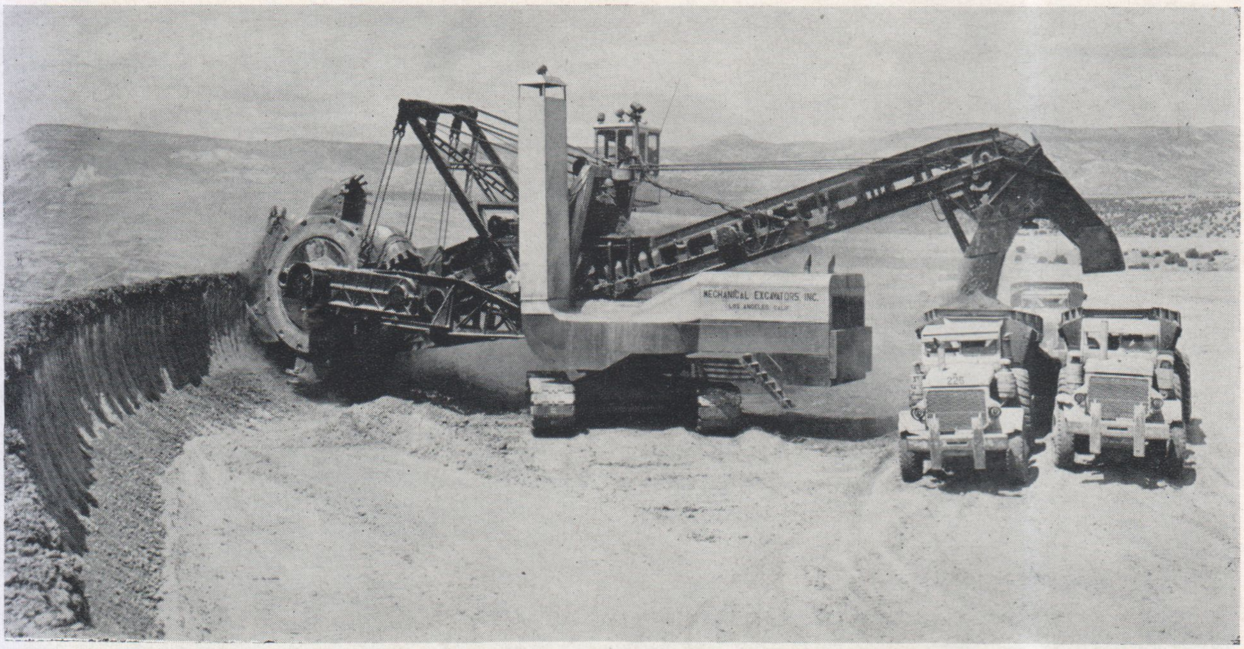

Fig. 1. The wheel excavator digging in a 12ft face

Wheel Excavator at Abiquiu Dam

This article describes the use of a 2,000-yd^3 wheel excavator developed by the contractor for this dam in New Mexico. All the materials were transported 4,300ft on a belt conveyor and passed through a processing station

By IAN B. MACKINTOSH*, M.A., A.M.I.C.E., M.ASCE.

ABIQUIU dam (pronounced "Abbeycue") is a key structure in the United States Army Corps of Engineers comprehensive programme to bring flood and sediment control to the Rio Grande and its tributaries in New Mexico. This is an arid region where annual rainfall ranges from 8–12in. The Rio Chama, at times of high flow due to snowmelt or rains, carries as much mud as it does water, having eroded the light soil. The sediment tends to choke gravity drains in irrigation systems. The flood peaks of the Rio Chama and the Rio Grande can coincide devastatingly at their confluence at the town of Espanola, N.M., adding considerable flood damage to the depradation caused by sediment. The reservoir formed by the dam has a capacity of 1,762,000 acre-ft of which 1,200,000 acre-ft is available for flood control. The dam, which is on the Rio Chama, is a conventional earthfill type containing $11\frac{1}{2}$ million yd^3 of fill. It has a maximum height of 350ft (see Fig. 3). From heel to toe at river bed level the dam measures 2,650ft. The crest length is 1,500ft. There is a 140ft-deep grout curtain under the dam. The material classifications and volumes were as follows:—

Impervious—1,400,000yd^3. No stones over 4in size. At least 40% passing No. 200 screen.

Pervious—900,000yd^3. No stones over 6in size. Less than 8% passing No. 200 screen.

Random—9,300,000yd^3. No stones over 6in size.

There is no separate zone designated filter material. As the embankment cross section shows, the pervious

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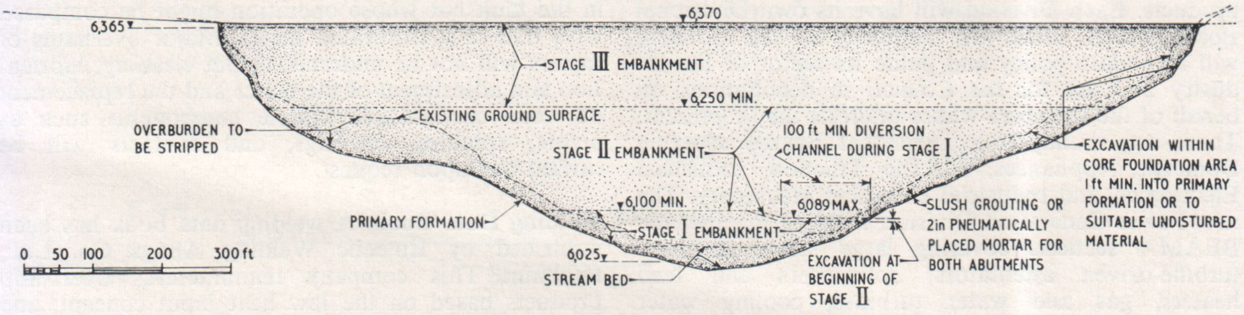

Fig. 2. Profile of abutment excavation for Abiquiu dam

zone fulfils the drainage function, being used on the outer shell of the upstream face of the drawdown range, and also as an annular border 10ft wide on the three sides of the random zone which forms the downstream shoulder.

The embankment fill is taken from borrow pits in an area where different sizes are found at different levels. In one section materials between 6ft and 14ft below the surface are suitable for the impervious zone if mixed together. Below this level is pervious material with about 12% oversize, and elsewhere the same zones exist at different levels, but usually mixing is required for the impervious zone and for this reason excavation by a face shovel or similar equipment is necessary.

The borrow pit is about two miles away from the dam and to avoid building a haul road across a canyon with some 200,000yd³ of earthwork, a conveyor was used to transport embankment materials a distance of 4,300ft. Trucks transport the material from the excavator to the conveyor and also from the conveyor to the dam. Another factor favouring the use of the conveyor was the processing required to remove the oversize and, if necessary, the fines.

Mittry Construction Company have the $8·5 million contract, which was let in February 1959, for the construction of the dam, which does not include the diversion tunnel or any concrete works. The spillway is an unlined side channel. Mittry pioneered the "Mole"*, a machine for tunnelling through shale, at Oahe dam. They have now developed and built themselves a very economical excavator which has been such a success on this project that they are going to manufacture and sell the machine for anybody who wants one. The dam was completed in February 1963.

Wheel Excavator

The purpose-made wheel excavator is built up on the undercarriage of a Lima 1250SC dragline ($3\frac{1}{2}$yd³) with heavier tracks than usual to carry its 160 tons. The machine has a ladder fitted with a wheel of six $1\frac{1}{4}$yd³ buckets which rotate at 9rpm. The buckets dig progressively into the face as the ladder swings slowly across the face taking a shallow bite out of the face. As the buckets rise over the top the material falls on to a chute and is directed on to the 60in boom conveyor which carries it to the 60in tail conveyor whence it is discharged into bottom-dump trucks. A two-way air-operated splitter enables the discharge to be transferred immediately to another truck standing alongside as soon as the first truck is full, thereby making loading continuous. This transfer is controlled by an operator with a portable transistor transmitter. An earlier form of the machine used a loading hopper but this is now dispensed with. The crew on the wheel consists of an operator, an oiler, a chute man and a dozer driver. On later models the chute man will not be necessary.

The cutting force at the tip of the bucket teeth is 15 tons, which can dig into very compact materials including shale, conglomerate and other soft rock. The excavator travels parallel to a vertical face of material up to 25ft high. The wheel takes a cut on an arc of about 90° as it swings automatically into the face. After the wheel has swung clear of the face the machine moves forward automatically as desired either 6in, 12in, or 18in, and starts a reverse swing. The speed of the wheel and swing can be speeded up or slowed down by depressing one of two electrical control buttons. As the buckets are only taking a shallow cut on the face the material is broken down into small lumps and in stratified material very uniform mixing is achieved. Boulders were rejected by scalping at the receiving hopper at the belt. The pervious material at Abiquiu dam is an extremely hard cemented gravel and the face remains vertical. After completion of the dam, to test the capability of the wheel further, about 100,000yd³ of sandstone were dug at a rate of 1,600yd³/h. To load this material with a shovel would have involved drilling and blasting.

The wheel excavator is described as the model 2000 because it has a loading capacity of 2,000yd³/h. The unit has two GM 12-V71 turbo-charged diesel engines. One operates the wheel and the crawling and the other powers a 250kW generator which drives the conveyor belts and the hoist which may be used to raise and lower the ladder. The Abiquiu wheel has excavated and loaded about 8,000,000 bank yd³ of material and has averaged 1,862 bank yd³/h with an availability of 85·6%. In the impervious material it reached a peak of 2,530 bank yd³/h.

A wheel excavator is very economical on account of its very high output in relation to its capital cost. At Abiquiu dam even with the high modification expense of the prototype machine the loading cost has been 4·5 cents/yd³. Under the name of Mechanical Excavators Inc., Mittry is offering a model 2000 for sale at $463,000. To equal this loading capacity would require four 6yd³ shovels (capacity 500yd³/h each) at a total cost of about $1,200,000. Apart from the much higher cost per yd³ of loading with 6yd³ shovels the corresponding hauling cost is also higher owing to the lower output of

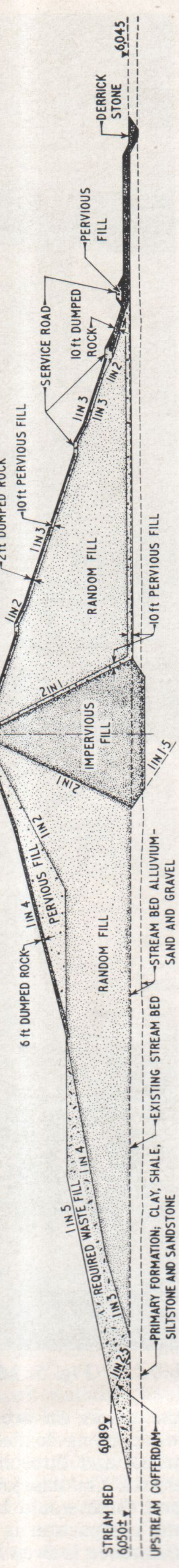

Fig. 3. Section through Abiquiu dam

* See WATER POWER, "The Great Lake Power Development," by Colebatch, Paxton and Endersbee, August 1963, p. 317, and "South Saskatchewan River Project," by Mackintosh, September 1963, p. 361.

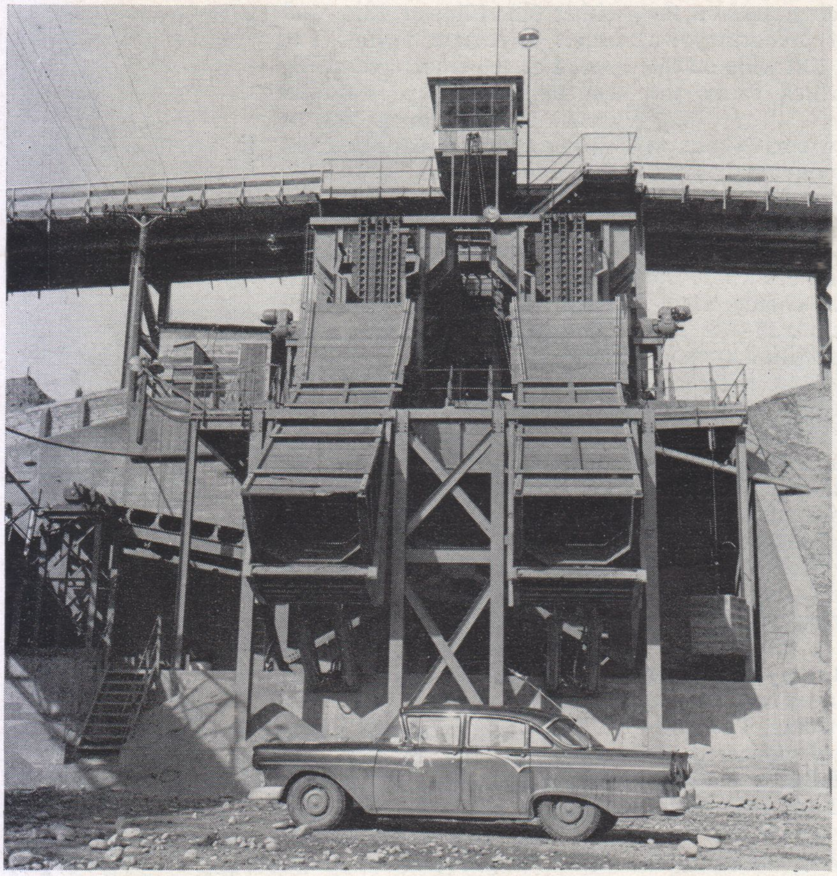

Fig. 4. Dumping station, showing rejects chutes for oversize

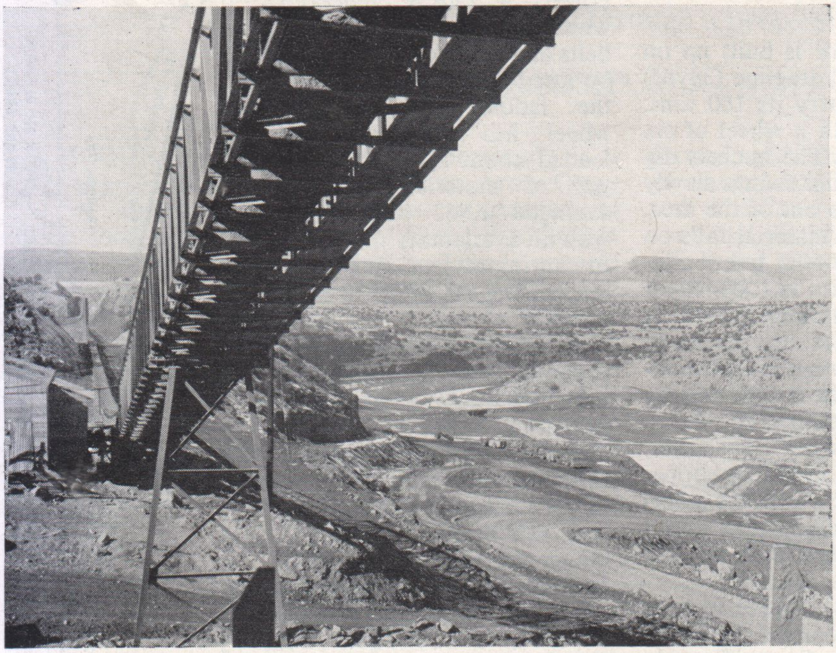

Fig. 5. Main conveyor belt seen from loading station

the trucks on account of the longer standing time while being loaded, which is one minute with the wheel and three minutes with the shovel for 40yd³ trucks. On this job Mittry were using 21yd³ trucks and these would be too small for a 6yd³ shovel. If the comparison is made for 4½yd³ shovels the cost difference is even larger.

Mittrys had on this contract four Lima shovels (one 5yd³, one 4½yd³ and two 4yd³). These were used for loading 6½ million yd³ of the 14½ million yd³ of borrow excavation. The materials in the borrow pit average 100lb per bank ft³. After compaction in the dam the density is increased to 130lb/ft³.

All materials from the wheel excavator are hauled to the dumping station, a distance of up to 1½ miles which averages ¾ mile, by Euclid 17yd³ bottom-dump trucks side-boarded to 21yd³. The trucks discharge into a 40ft-long receiving bin over which they travel. On a typical 1¾-mile round trip the cycle time is 4½min with speeds of 35–40mph. On the longer hauls 13 machines are used with four spare machines being serviced. These trucks have a total of 15,000 hours on them and have an availability of 90%. They have 300hp GM6-110 two-stroke diesel engines which are the original ones. The main lighting for equipment operating at night is on the machines themselves, but there are a few mercury-vapour floodlights of about 1,500W.

The haul from the loading station to the dam is 1,500ft. On this work there are seven more 21yd³ bottom-dump trucks making a total of 24 on the whole job. There are also six Euclid 23TDT 18yd³ scrapers whose tractor units are interchangeable with the bottom-dump trucks. They are used for placing the fill on the dam although primarily they were used for stripping the borrow area.

Belt Conveyor

Before work was started it was expected that it would be necessary to process the impervious materials to meet the specifications on fines, and for this reason separate bins and screens were provided at the loading station near the dam. In the event this was not necessary and careful material selection in the borrow area enabled the fines specification to be met without processing, so all the material at the loading station went through one bin and the other two were not used. All placing was concentrated on one material at a time and all the equipment handled this for perhaps a week before switching over to another material.

The dumping station at the intake end of the 4,300ft-long belt conveyor is at the top of a ramp, which can be used for decelerating and accelerating, and the bottom-dump trucks straddle the 40 × 15 × 12ft deep 10-load hopper (three loads are dead). From the open bottom of the bin there are two endless steel belts consisting of 60 × 8 × ½in steel plates. These feed the material on to two vibrating screens from which the over 6in material is passed into a waste bin, and is then hauled away to a waste pile by trucks. The remaining material goes through the screens to two transfer conveyors which take it to the main 48in belt running at 800ft/min. The material is weighed on the belt and a continuous record is automatically made. The conveyor is carried on a high trestle across a deep ravine at one point.

The driving power for the belt was most unusual in that it was direct mechanical drive by diesel engines at a single driving point. Mittry's point out that this is more efficient than electric power and claim that it need be no less reliable. The diesel engines used were two General Motors "quads" coupled together, giving a total power of 1,200hp. A quad is a combination of four GM6-71 two-stroke diesel engines mounted on a single bedframe and driving a single shaft. The quads are in the same power house and the shafts drive a torque-converter gearbox directly to the belt. The availability of the belt conveyor has been about 90% and there has been only one major breakdown, a gearbox failure. The belt rises from El. 6,120ft at the dumping station to El. 6,270ft at the loading station which is located on a bench at El. 6,190ft, level with the top of the upstream waste zone of the dam. The crest of the dam is at El. 6,368ft and the river bed at El. 6,020ft. A little over 50% of the material in the dam is below the elevation of the loading station. The cost of the complete conveyor, which was supplied by the Conveyor Company of Los Angeles, was $1 million. One man controls the conveyor, and the complete crew consists of one operator, one oiler, four labourers, one power-station attendant, one mechanic and one dozer driver at the dump station.

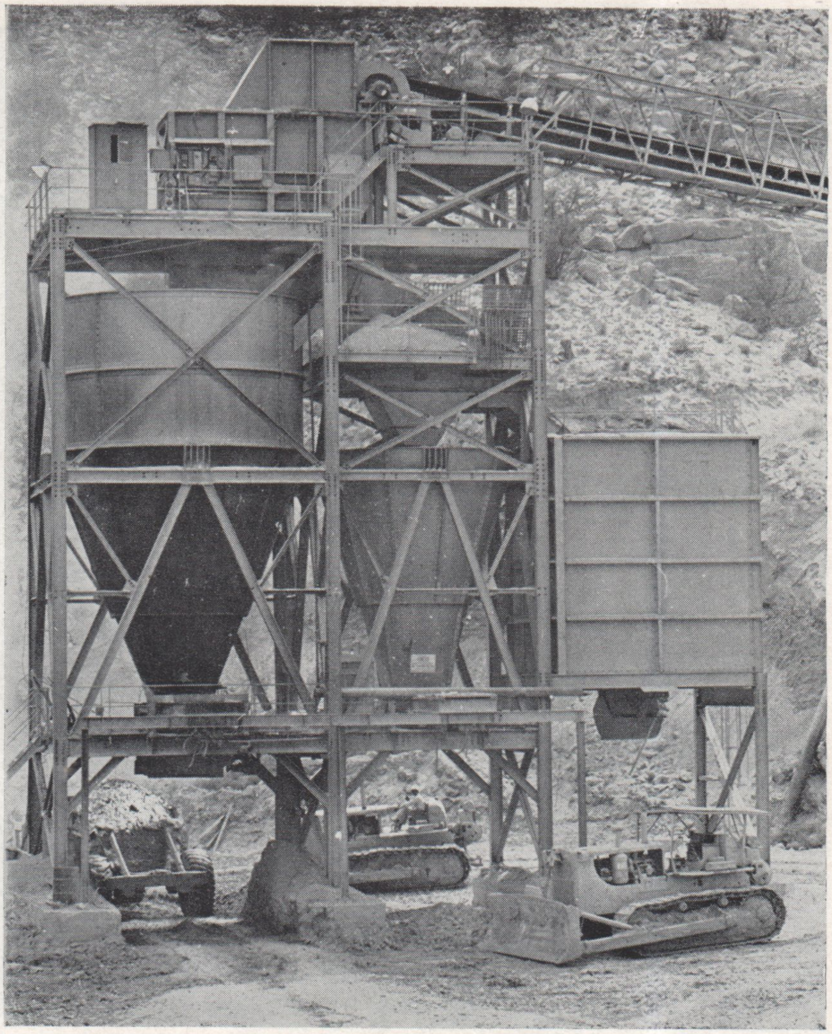

Fig. 6. The loading station at the conveyor delivery

Moisture Control and Compaction

The natural moisture content of the materials is between 4 and 8% and the optimum 11 to 14%. The impervious zone must be compacted at a moisture content of between 1% and 2% below optimum. The moisture is introduced at the loading station as the material comes out of the hopper. The drivers pull a lanyard which actuates air-operated roller gates set to remain open for 8½sec during which time 18yd³ of material is discharged. This works automatically when the bin is more than half full and a light indicates to drivers whether the bin is full enough. A gadget in the chute just below the roller gates sprays the earth with the right amount of water as it falls, striking five 5in angles spaced out 1ft apart. Below each angle are two 4in-diameter pipes one above the other perforated with 28 ½in-diameter holes which spray upwards and outwards. The flow of water from two tanks 75ft up through a 16in pipe is controlled by solenoid-operated valves. Four switches are installed on the gate and as it opens it strikes them in sequence so that only when earth is falling past a set of sprays is the spray discharging water. By this means moisture can be controlled within ½%.

The advantage of adding water as the material is discharged from the loading station, rather than in the borrow pit, is that the clay is very sticky and this would be a hindrance not only at the wheel excavator but also on the primary haul and on the belt conveyor. On the haul to the embankment water soaks uniformly into the earth and usually no additional watering was necessary but when required an 8,000gal water-tank wagon drawn by a Cat DW21 did this; normally this unit was at work watering haul roads. The normal output of embankment placing was 500,000yd³ per month. The bottom-dump gates of the trucks enable a windrow laid at 10mph to be spread to specified depths with one pass of a D8 bulldozer mounting a scratch bar with 16 teeth in two rows. On the return pass the dozer operator drops the scratcher low enough to penetrate the previously

Fig. 7. Embankment construction in progress. Note the dump truck being lowered by a bulldozer to place riprap

compacted layer about 2in and the material is then ready for rolling.

Rock excavated in the 130,000yd³ spillway channel, which has a 40ft bottom width, is used for slope protection on the faces of the dam. Blast holes are drilled by Gardner Denver Airtracs which drill 35ft holes on an 8ft by 9ft spacing with 3½in bits. Dry drilling is used and the normal output is 600–700ft in a ten-hour shift. The rock is quite hard and as there is no open face the explosive ratio is 1½lb/yd³. Ammonium-nitrate fuel-oil explosive AN/Fo was used and Mittrys mixed it themselves. A 4½yd³ Lima shovel loaded into 22-ton Euclid rear-dump trucks, and an output of 200–250yd³/h was obtained. The upstream face of the dam is to be covered by a 6ft thickness and the downstream face a 2ft thickness of the dumped rock. Sandstone is specified and the waste cobbles were not acceptable. The slopes vary from 1 on 3 to 1 on 4 and the 22-ton Euclid rear-dump trucks are lowered down the slope backwards by a D8 tractor with a wire rope (see Fig. 7).

The estimated quantity of foundation and abutment excavation for the dam at the time of bidding was 1,750,000yd³. When the contractor was half-way through stripping down the abutments the extent of the excavation was increased and it was necessary to come down the abutments again with a second cut. There were further modifications as the foundation was exposed and the final total for this item was 3½ million yd³, representing an overrun of approximately 100% on the estimated quantity. This caused a major shutdown in September 1960. Shovels of 4½yd³ capacity were used for the abutment excavation, when in good material and with a good operator production was about 500yd³/h.

Under the dam there is a 140ft-deep grout curtain. Holes were 1½in in diameter and were spaced on 10ft centres. Grouting was performed by stages. First, holes were grouted at 40ft centres, next at 20ft centres and finally at 10ft centres. The holes in the abutments were first grouted at 20ft centres and finally at 10ft centres. The total quantity of grout used in the grout curtains was 39,800ft³.

The outlet works were completed under a previous contract before the start of the embankment contract. A small cofferdam or diversion dam was constructed upstream to divert river flow through the 2,300ft-long 12ft-diameter concrete-lined outlet tunnel, and a second small cofferdam was built at the outlet end of the tunnel to prevent backflow into the dam area. Each cofferdam contained about 1,500yd³. The upstream dam was incorporated into the waste fill, and the downstream dam was removed after the main dam was built to a safe height. The outlet tunnel

Fig. 8. A view of work on the embankment

handled all river flow during construction of the dam.

Prices and Payments

The materials in the dam are paid for in two parts—first, for excavation in borrow pits measured in bank yards, and this includes processing and transport, and secondly for placing and compaction on the embankment measured in place in the dam. The unit prices are as follows:—

	yd^3	Unit price $
Excavation unclassified	3,500,000	0·72
Excavation in rock	130,000	1·50
Excavation in borrow pit ..	14,500,000	0·42
Embankment fill	11,600,000	0·055
Dumped rock on slopes ..	250,000	1·00

Other Sizes of Wheel Excavator

Mechanical Excavators, Inc. (2960 Marsh Street, Los Angeles 39, California) are offering six models of wheel excavator as follows:—

Model No.	Type	Capacity yd^3/h	Price $
3000	Crawlers	3,000	711,000
2000	Crawlers	2,000	463,000
1000	Crawlers	1,000	294,000
700	Crawlers	700	163,000
500	Rubber Tyres	500	143,000
300	Rubber Tyres	300	123,000

Wheel excavators were built in Germany for moving brown coal in the 1920s, and the present-day versions of these wheels are said to be much more cumbersome and elaborate than the Mittry wheel and consequently have much greater capital and operating costs. An example is a Krupp wheel excavator being purchased by Peabody Coal Company for use on coal stripping in Kentucky, which it is said costs $5 million and has an output of 3,000yd^3 per hour. The basic difference is said to be that the material does not change direction in the Mittry wheel, which is comparable in output to that of German wheels of twice the diameter.

Acknowledgments

Colonel John F. Arfman was District Engineer for the US Army Engineer District, Alberquerque, and Donald H. Wilson was the Corps' Resident Engineer at Abiquiu. Mittry Construction Company Project Manager was its President, F. K. Mittry Jr., and their Project Engineer was Jack Starkey. The author's thanks are due to the Corps of Engineers and to the contractor for their kind assistance during his visit to the dam and for help in preparation of this article.

From page 502

Dr. Leopold Müller described the influence of blasting on the strength of a rock mass. It has long been known that shock waves due to blasting will have a loosening effect on a rock mass, but the enormous decrease in strength that results from such loosening is not generally realised. Recent studies of the effects of blasting on rock masses have shown that a decisive weakening may result from only slight concussive shock. The sensitivity of a rock mass to such shock waves is determined by stress concentrations at the end of joint fisures as well as by tensile stresses in the vicinity of the joints. The character and orientation of the joint structure and the degree of separation of the joints are therefore critical factors. Filling materials within the joints may be beaten out by the concussions, to weaken frictional contacts at the joints, while, in addition, the degree of separation at the joints may be increased. Thus the tensile strength and the shearing strength of the rock mass may be diminished.

Investigations on in-situ rock masses, as well as model studies in the laboratory, have shown that the effect of blasting may extend far beyond the extent that is evidenced by the immediate rock fracture, but such depth effects can be alleviated by appropriate measures. A great number of possible blasting techniques are available and the most suitable ones are not always chosen. This is unfortunate both from the aspect of efficiency in working and for the safety of personnel.

The Colloquium concluded with the showing of two films from the Lawrence Radiation Laboratory of the University of California. These films, entitled "Nuclear Excavations" and "Project Sedan," described some of the features of and results obtained from the underground nuclear test explosions in the United States of America.

The papers presented at the Colloquium are to appear in full in *Rock Mechanics and Geological Engineering* which has now succeeded *Geologie und Bauwesen,* edited by Dr. Leopold Müller, and published by Springer-Verlag, Vienna.