Presplit Blasting Procedures, Bull Run Steam Plant, Clinton, Tennessee

ROBERT G. STANSFIELD and JOHN M. KELLBERG
Respectively, Civil Engineer and Geologist, Tennessee Valley Authority

Geologic conditions and design requirements at the Bull Run Steam Plant presently under construction by the TVA 13 mi west of Knoxville, Tenn., dictated close control of blasting procedures to obtain safe and economical excavations. Various techniques of presplit blasting were used in the initial stage of all major excavations and other specialized loading and detonation patterns were used in later stages.

Hole diameters for presplitting varied from 1½ to 9 in., and hole spacing ranged from 12 to 33 in. on centers. Charges varied from ½ lb to 175 gr per lin ft of hole. For both 9-in. diameter holes and the 2¾-in. diameter holes, the cost of materials was less than $0.10 psf of face developed; however, drilling and labor costs were considerably higher for drilling and loading the larger diameter holes.

Using the presplit method, clean vertical walls up to 70 ft in height were obtained in moderately dipping, though complexly sheared and jointed argillaceous limestone. As the work progressed, the presplit program was modified to meet the varying geologic conditions and job requirements.

This work was done on a production basis. Therefore, refinements and experimentation normally carried on in a research program could not be fully utilized. It is felt, however, that the methods developed on this project could have useful applications on other major projects and in highway construction.

•SINCE ITS DEVELOPMENT in 1958, presplit blasting has become an accepted method of obtaining essentially smooth, vertical walls in rock excavation. The usual technique has been to drill a line of vertical blast holes spaced from 1 to 2 ft on centers, generally to the depth of the required cut. These holes are loaded with charges made up of 1¼- by 8-in. cartridges of 40 percent strength explosive spaced at intervals of 12 to 24 in. along a length of 50-gr detonating fuse. A slightly heavier charge is customarily placed at the bottom of the hole, whereas the charge is somewhat reduced near the ground surface. Explosives usually are not attached to the detonating fuse closer than 2½ ft from the top. After filling with sand or stone chips, the holes are detonated simultaneously, thereby splitting the rock in the plane of the drill holes. Often a crack so developed will be several inches wide at the ground surface, evidence of the slight displacement of the rock near the surface. Drilling and blasting to fragment the rock to be removed then follows.

The Tennessee Valley Authority is presently constructing the Bull Run Steam Plant, 13 mi west of Knoxville, Tenn. (Fig. 1). Geologic conditions at the site, together with design requirements, dictated close control of blasting to obtain safe and economical

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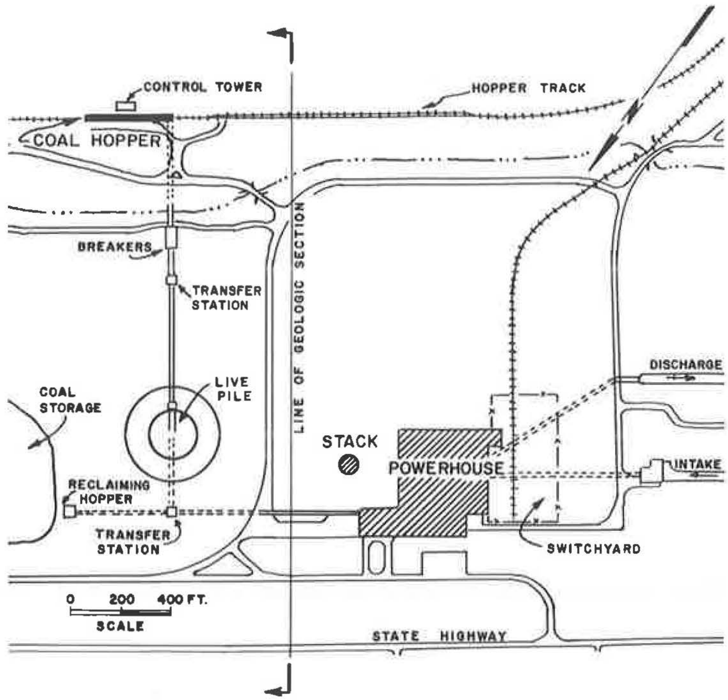

Figure 1. Generalized plan of plant structures.

excavations. Presplitting was stipulated for this project to help provide smooth rock walls to serve as forms in concreting, as well as to reduce overbreak.

The Bull Run site occupies a northeastward trending valley approximately 2,000 ft wide, flanked by ridges which rise 300 to 400 ft above the valley floor. This valley is underlain by a stratigraphic thickness of 1,800 ft of thin-bedded Middle Ordovician Chickamauga limestone and siltstone which dip to the southeast at an average of 30 deg (Fig. 2). Along the ridge to the southeast, the top of the Chickamauga is truncated by the Copper Creek fault, a major Valley and Ridge structure, which in this locality has thrust the Lower Cambrian Rome sandstone and shale over the Middle Ordovician limestones. Minor shears and thrusts associated with the Copper Creek fault are common in the underlying Chickamauga formation, and these usually dip southeastward at a steeper angle than the bedding.

Before start of construction, 363 core holes totaling 24,600 lin ft were drilled in two exploration programs. The first program developed the suitability of the site and the second delineated the foundation conditions at the locations of major structures. Analysis of the drilling data indicated that special methods would have to be used and certain precautions taken in excavation to maintain stable cuts in the moderately dipping and complexly sheared argillaceous limestones and siltstones. The preliminary orientation of the powerhouse was turned 90 deg so that a dip slope would occur only across the northwest end of the first unit and would not be a factor in the construction of any succeeding units; even so, excavations for the intake and discharge conduits and for the coal-handling facilities could not avoid dip slope faces.

New procedures for presplitting were developed to utilize holes of various diameters, as the availability of drilling equipment largely determined the size of the hole used. These varied from 1½ up to 9 in. in diameter.

The two main rock excavations were for the powerhouse and for the coal-unloading facilities. A low ridge at the powerhouse site was excavated to the general plant grade.

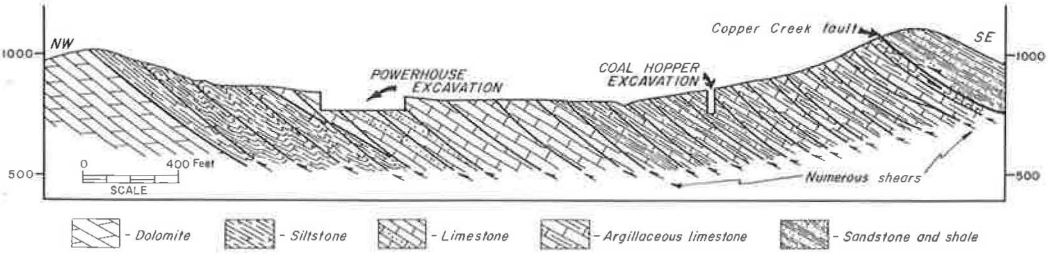

Figure 2. Generalized geologic section, Bull Run steam plant.

The average depth of the excavation from this level was 40 ft. A width of 175 ft and a length of 375 ft defined the rock excavation of 100,000 cu yd. Vertical rock walls designed for the powerhouse excavation made an access ramp necessary, also having presplit walls (Fig. 3).

The general practice in the powerhouse area was to drill the presplit holes to the full depth of the desired wall. Holes were centered on various spacings in a line 6 in. behind the desired neat line. The procedure first used was to drill $2\frac{3}{4}$-in. holes spaced on 12-in. centers with only every other hole charged with explosives. Following the customary practice, the presplit charges were made up in the field (Fig. 4). A length of detonating fuse about 18 in. longer than the length of the hole to be loaded was strung out on planks at waist level for convenience. One-half pound of explosive in the form of a $1\frac{1}{4}$- by 8-in. cartridge of 40 percent gelatin was secured to the end of the detonating fuse which would be at the bottom of the hole. Half cartridges were secured at 12-in. intervals along the fuse. Charges near the top were reduced to one-third of a cartridge and stopped 4 ft from the end. Charges thus assembled were lowered into the hole followed by stemming of $\frac{3}{8}$-in. stone chips or sand. The detonating fuses from the loaded holes were attached to a trunkline of fuse, and the shot fired by electric blasting caps secured to the trunkline. Even these relatively light charges occasionally produced slight fractures extending into the wall rock behind the charged sections of the drill holes. Presplit results were satisfactory along the butt slope and end walls. However, rock on the dip slope was often displaced along one of numerous moderately dipping shear planes, either by presplitting or by the excavation blasting that followed.

Because of the availability on the job of a large rotary drill, 9-in. diameter

Figure 3. Presplit face parallel to dip of rock strata in powerhouse access ramp.

Figure 4. Assembly of presplit charges.

holes were introduced into the presplit program. At the powerhouse site, these large diameter holes were centered 6 in. behind the neat line and spaced 33 in. center-to-center. A $2\frac{3}{4}$-in diameter hole was drilled halfway between adjacent 9-in. holes. Only the $2\frac{3}{4}$-in. holes were loaded; the 9-in. diameter holes were left open. Results from this method were comparable to those obtained when all holes were $2\frac{3}{4}$ in. in diameter.

As the excavation program uncovered sections of the rock walls that had been presplit by procedures so far described, observations of the drill hole scars indicated that the practice of loading only every other hole in line should be eliminated. The scars showed that the plane of presplitting was determined by the axes of the holes that had been charged. Often, if the unloaded hole between two charged holes was out of the plane established by these two holes, the resulting presplit surface did not deviate from this plane and bypassed the off-line hole. If an unloaded hole drifted a distance equal to or greater than its diameter, only that section of the hole circumference within the established plane was split. Thereafter, every presplit hole was loaded; charges or spacing were altered to obtain the maximum results.

In the interest of better control and safety, 1- by 4-in. cartridges of explosives were purchased, replacing the $1\frac{1}{4}$- by 8-in. sticks originally used. When cutting and using portions of the 8-in. cartridges, small particles fell from the open end. The 1- by 4-in. cartridges eliminated the hazard associated with the accumulation of loose explosive on the ground in the work area. It also made the use of reduced charges more practical, as the 1- by 4-in. cartridge is about equal in volume to one-third of a $1\frac{1}{4}$- by 8-in. cartridge. The increase in the cost per hundredweight of the smaller cartridge can be balanced by using less expensive semi-gelatin explosives as the cartridges are left intact.

In using $2\frac{3}{4}$-in. diameter holes and loading every hole, the spacing between hole centers varied from 1 to 2 ft, depending on the depth, location, and rock conditions. Good results were obtained when charges were assembled with 1- by 4-in. cartridges secured to 50-gr detonating fuse at intervals of 18 in. for the holes spaced on 1-ft centers, and at 12-in. intervals for holes spaced at 2 ft.

Experience, at this project and others, has shown the tendency for the development of fractures radiating from the presplit blast hole into the wall rock. These radial fractures are induced by the detonation of the charges on the presplit "string." Furthermore, under favorable geologic conditions, rock movement or destruction of the bond along joint or bedding planes can take place with the normal loading used in the conventional presplitting method.

To prevent such effects under the adverse rock conditions known to exist at the site of excavation of the coal-unloading hopper, a method was required that would minimize movement along shear, joint, and bedding planes, as well as the fracturing of the rock behind the presplit line. Before start of excavation in the hopper area, a detonating fuse of 175 gr of explosive per lin ft was successfully tested as the only explosive in presplitting the shallow excavations for the cable tunnel and for the circular chimney foundation. Manufactured for use as a high-strength detonator of relatively insensitive explosive mixtures, this fuse, 0.43 in. in diameter, contains 3 to 4 times more explosive than does conventional fuse.

This detonating fuse used without attaching other explosives has the advantage of an even, continuous charge the full length of the blast hole. The energy is not concentrated at the intervals of attached explosives. In practice, this eliminates the radial fractures occasionally induced in the back of the hole at the charge intervals. Because of the reduced charge—437.5 gr = 1 oz—the chance of rock movement is greatly lessened.

The rock excavation for the coal-unloading hopper was the most difficult encountered at Bull Run. It required a trench 360 ft long, 27 ft wide, and up to 70 ft deep (Fig. 5). This vertical-walled excavation was nearly parallel with the strike of the rock strata in the dipping and sheared argillaceous limestone, 400 ft below a major overthrust fault (Fig. 2).

Two 25-ft wide ramps for the conveyor tunnels enter the hopper at right angles from up dip on a 22 percent descending grade. Both conveyor ramps are designed with vertical walls. One ramp enters the hopper at the extreme southwest end, and the second joins the excavation nearly in the center of the 360-ft length. These parallel ramps,

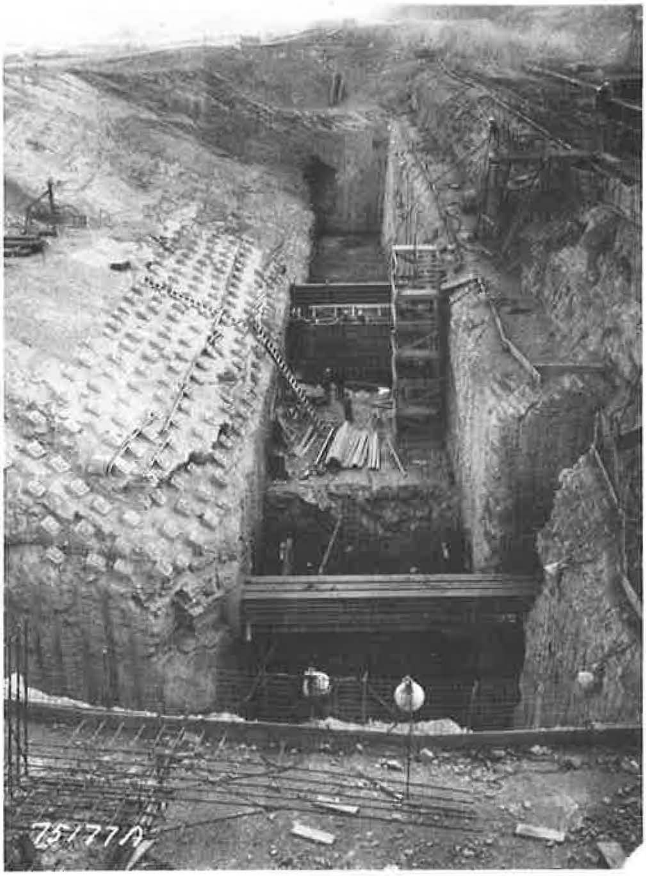

Figure 5. Presplit faces parallel to strike of rock strata in coal hopper excavation.

each approximately 240 ft long, isolate a mass of rock and overburden on the northwest slope of the hopper, 134 ft wide and 70 ft high. The slope is underlain by numerous shear planes at angles of 30 to 45 deg dipping into the hopper excavation. Positive, protective measures were taken to insure stability of the dip slope but these are not within the scope of this paper.

In presplitting the excavations for the unloading hopper and conveyor tunnels, both 2¾-in. and 9-in. holes were used. All holes were started 6 in. behind the desired line and drilled the full depth of the rock wall. The deepest 2¾-in. hole presplit was 70 ft, whereas 50 ft was the greatest depth for a 9-in. hole.

The necessary split without displacement or radial fracturing was obtained along the northwest and southeast face of the hopper, and in the upper end of the conveyor excavations using 2¾-in. holes. Although this size hole was drilled initially up to the full 70-ft depth, presplit loading did not exceed 35 ft. Many of the holes were blocked by loose rock and mud which could not be cleared with compressed air for the total depth. When the upper 35 ft of rock was removed, the presplit holes were reopened and loaded the remaining depth.

Along the northwest and southeast walls of the hopper, a network of intersecting, high-angle, recemented shear planes was potentially hazardous if disturbed. Here, holes were spaced on 12-in. centers, and charged by lowering a strand of 175-gr detonating fuse, doubled for 5 ft at the bottom end.

Equally good results were obtained along the conveyor walls with 2¾-in. diameter holes spaced up to 2 ft on centers and charged the full depth with two strands of 175-gr fuse. The strands were kept from spreading by taping at 6-ft intervals (Fig. 6).

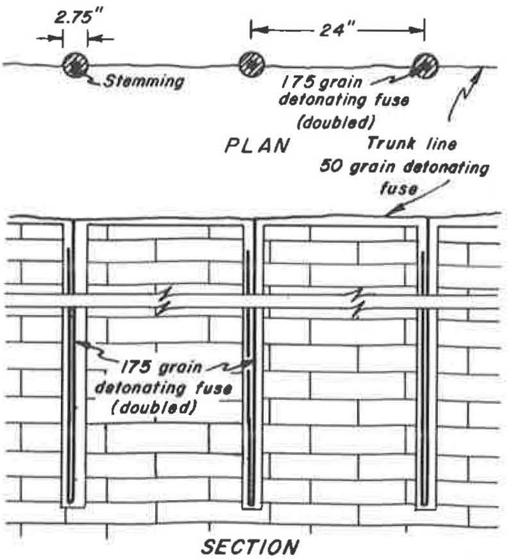

Figure 6. Presplitting with high-strength detonating fuse.

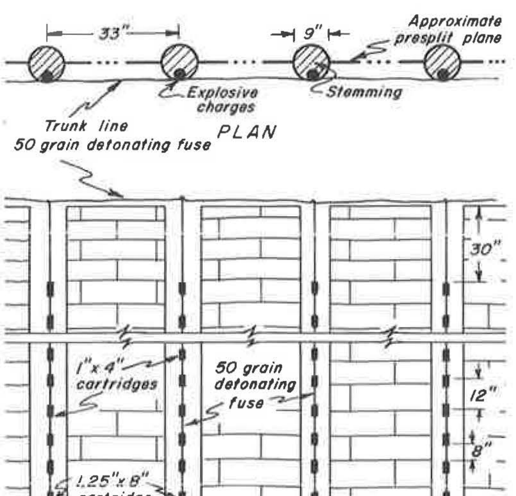

Figure 7. Presplitting with "off-center" loading in large diameter holes.

Holes of 9-in. diameter had been used in presplitting at the powerhouse site where alternated with $2\frac{3}{4}$-in. diameter holes. In the excavation for the southwest end of the hopper and sections of the conveyor conduit walls a different presplitting technique using only 9-in. holes was developed. These holes were drilled in line on centers up to 33 in. The presplit charges were 1- by 4-in. cartridges of 40 percent strength taped to 50-gr detonating fuse at 12-in. intervals with a $1\frac{1}{4}$- by 8-in. cartridge at the bottom. The explosive string was placed along the side of the 9-in. hole toward the excavation side of the presplit line, and the hole was then filled with stemming (Fig. 7). As the 9-in. rotary-drilled holes were plumb, no difficulty was experienced in being able to load in this manner. This technique has the advantage of giving direct contact of the explosive with the rock to be removed. At the same time, the side of the hole that adjoins the rock surface to be preserved, is protected by a thickness of stemming material nearly equal to the diameter of the hole. Good presplit surfaces resulted and the plane of rupture still extended approximately through the center of the holes.

To retain sound rock walls in the final excavation, care must not be limited only to presplit blasting. At Bull Run, emphasis was placed in planning the drilling and millisecond delay excavation blasting, not only to fragment the rock for economical handling, but also to reduce the amount of energy transmitted across the presplit plane to a point where damage would not result to the wall rock. The blast patterns and criteria for fragmenting the rock to be removed cannot be covered in this paper, but it should be emphasized that without such care the presplit surfaces at Bull Run could not have been preserved.

The best cost figure for materials per square foot of presplit surface blasted, using $2\frac{3}{4}$-in. holes, was \$0.06 compared with \$0.07 for the 9-in. holes. These figures are based on spacing the smaller holes 2 ft on centers and include the cost of a double line of 175-gr detonating fuse and stemming material. The figure for the larger diameter hole is based on 33-in. spacing, center-to-center, and includes the cost of 1- by 4-in. cartridges, 50-gr detonating fuse and stemming material.

Although the cost of materials for both size holes are similar, it can be readily understood that the costs of drilling and assembling charges for the large diameter holes are considerably higher than for the $2\frac{3}{4}$-in. holes. These material costs reflect the light explosive loads used at Bull Run. Naturally, variable conditions of type of rock and the results desired would alter these costs.

It is believed that the presplitting procedures developed at Bull Run could be successfully adapted to rock excavation in highway construction.

At Bull Run 175-gr detonating fuse was used as the only explosive in small-diameter jackhammer holes to presplit footing excavations and sumps; also, in trimming unsound rock from slopes. Similar uses would seem to be applicable in highway bridge foundation construction. This same technique could also be applied to trimming certain areas of unsound rock along existing roadways.

The off-center loading of large-diameter presplit holes would seem to lend itself to use on deep highway cuts. Under conditions less critical than those described, the use of heavier charges might well allow a substantial increase in the 33-in. spacing reported for the 9-in. diameter holes. Greater spacings would reduce the cost of presplitting with these holes and perhaps make fuller use of available drilling equipment at some operations.