# Construction and Feasibility Associated With Nuclear Excavation

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•THIS PAPER will cover the post-shot construction, cost estimates and conclusions of Project Carryall.

## POST-SHOT CONSTRUCTION

### Post-Detonation Access and Engineering

Following nuclear detonations and as soon as the Project Manager has determined that radioactivity has decayed sufficiently for work crews to enter, conventional post-shot engineering activity will begin. Access roads will be constructed into the channel to permit post-shot surveys and explorations. Photogrammetric controls will then be established and the crater and adjacent areas will be mapped. Detailed and precise design of the railroad and highway facilities will then be completed—all essentially in the same manner as for a conventional project.

The cross-sectional shape of the crater will approximate a parabola and it should be relatively smooth longitudinally, with variations perhaps as great as 5 percent of the apparent crater depth. The final alignments and grades of the roadbeds will then be adjusted to most economically fit the channel.

The minimum typical cross section generally used for construction on this freeway route provides for initial construction of two 12-ft traffic lanes with an outside 10-ft shoulder in each direction and a 100-ft median dividing strip that provides width for ultimate construction of two additional traffic lanes in each direction as well as adequate width for minimizing cross-median accidents and headlight glare (Fig. 1).

Within the crater area the initial two westbound lanes will be shifted 24 ft southward from their normal position and away from the adjacent crater slope, reducing the initial median width to 76 ft. This will be done to correspondingly increase the initial width of the adjacent rockfall zone to provide greater protection during early use of the highway. Here, the ultimate additional lanes will be constructed on the outside well after the slopes have stabilized and the ultimate median width will then match the ultimate conventional construction planned to the east and west.

The design will provide for double-track railroad construction along the southern lower channel slope, with a rockfall zone approximately 38 ft wide. The railroad grade will be about 22 ft higher than the eastbound highway grade to fit the channel slope and to minimize headlight glare.

### Roadbed Construction

It is assumed that all post-shot and post-survey construction work within the crater, except for railroad ballast and track, will be performed by a private firm under contract with the State in order to expedite construction without the conflict of two contractors working in the area at the same time. California's highway work is generally bid at unit prices, with comparison of bids on the basis of the Engineer's estimate. Also, the State generally specifies results rather than methods. It is contemplated that this work be so bid and performed.

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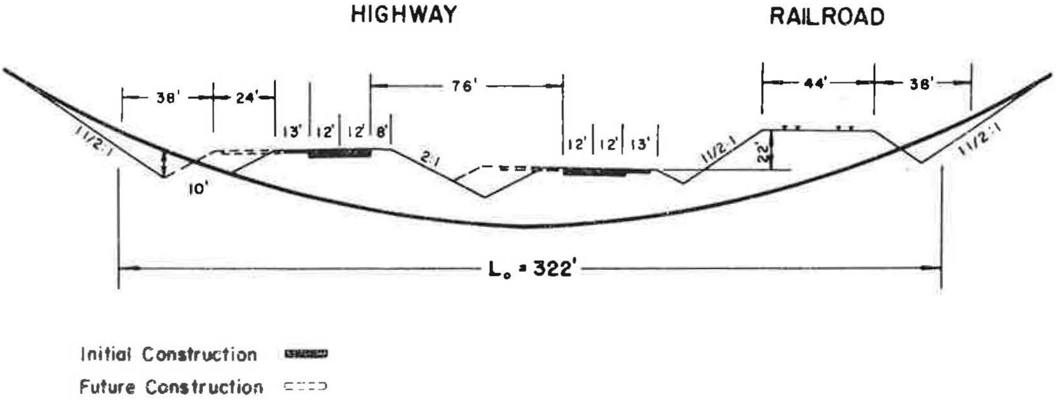

Figure 1. Typical cross section of final roadbeds proposed for Project Carryall.

The roadbeds will be constructed on embankment throughout the channel. The majority of the embankment material will be obtained from excavation areas at the ends of the channel. Because this will be predominately a rock fill, a 3-ft earth cushion is planned for the uppermost portions. This alluvium will be readily available east of the channel area. All embankment construction can be accomplished with normal construction equipment.

Rock excavation will be necessary to grade into and out of the nuclear-excavated channel. This rock has been classed as soft to medium hard, suitable for common excavation, and will be placed in the lower portions of embankment.

Excavation slopes of 2:1 ratio have been used for this study. It may be possible to increase this rate of slope to 1 ½: 1 or even steeper when the actual nature of the rock is determined after detonation. All excavation construction will also be accomplished with normal construction equipment.

Previous experience indicates that the resultant material in the channel fallback area will consist of broken rock particles ranging in size up to about 2 ft. This material will be in a point-bearing condition and should be similar to a rock fill confined on the sides and bottom by the true crater.

The lower portions of the fallback material should be well consolidated as a result of the force and vibration applied by the upper layers falling several hundred feet. The use of conventional earthmoving and compaction equipment in constructing embankment on the top of this material will result in additional consolidation in the upper layers. The mantle of alluvium used in the embankments themselves will provide a cushion for the finished roadways.

With the lack of rainfall and absence of groundwater in this region, no appreciable settlement problem is expected. However, settlement platforms will be placed at the bottom of embankments within the channel, especially over the deeper shot (and fallback) locations to detect and measure possible settlement and in turn permit and check the results of corrective measures, such as surcharging or additional mechanical compactive effort. If settlement occurs subsequent to construction and during use of the railway and highway facilities, it should be of a relatively uniform character and can be corrected by adjustment of the railroad track and ballast and, on the highway, by resurfacing with asphaltic concrete pavement.

Because this excavation will be in areas of medium hard to hard rock, the slope stability problem is more nearly related to the properties of the rock in the rupture zone outside the true crater walls than to the fallback in the crater. The stability of the material in the rupture zone depends on its resistance to shearing stresses imposed by the added load of the lip material. Because the thickness of overburden in this area is negligible, it can be assumed that the rock in the lip will be resting directly on rock in the rupture zone.

The character of the material involved will be determined during the preliminary site investigation phase. Additional channel width to provide a greater width of rockfall zone can then be planned to allow additional room for possible slides if conditions warrant. The added cost of increasing the device yield to allow for this extra width is relatively minor.

It is expected that the fallback material will reach a natural angle of repose shortly after detonation, except for minor raveling.

Post-shot investigation will be made of the possible need for scaling of loose rock and removal of potential slide material from the slopes. If indicated, this will be required of the construction contractor as a first order of work.

## Drainage

Preliminary investigations indicate that the voids in the channel fallback zone will be more than capable of absorbing all runoff from rainfall within the channel area. The depressed rockfall zones along each side of the channel will be extended with sidecut ditches at the western end which will provide outlets in the event the fallback zone becomes incapable of absorbing the entire runoff. Preliminary indications are that groundwater does not exist within the channel area.

Runoff from a minor drainage area south of the channel, and near the eastern end, will be diverted by the channel lip into the Orange Blossom Wash without crossing either the railroad or highway roadbeds. Another drainage area south of the channel and near the western end will probably be handled by dropping the flow into the adjacent rockfall zone and drainage ditch sloping to the west.

Orange Blossom Wash crosses the eastern end of the proposed nuclear alignment. Here the proposed roadbed grades are at elevations below the present flow line of the wash. One solution is to divert this flow east to a point where roadbed elevations permit passing it under bridges. However, the cost of three major bridges plus channel, dike and riprap slope protection construction would be quite high.

In lieu of such conventional construction it is proposed to handle the runoff from this wash and a smaller drainage area to the west by providing a separate nuclear crater in the bed of the wash upstream from the highway and railroad crossing (Fig. 2). A relatively minor amount of cutting through the lip will be required to train the

Figure 2. Model of Project Carryall showing drainage crater in relation to roadway excavation.

runoff into this crater, and a culvert will be provided to pass the runoff generated between the crater and the highway and railroad.

The maximum known thunderstorm occurring in this area was of 7-hr duration with a peak intensity lasting 3 hr. It is estimated that such a storm will deliver 3,450 cfs to the proposed crater for 3 hr with a total runoff volume of 850 acre-ft. This crater will be excavated with a 100-kt device and will be designed to provide an apparent crater volume of about 1,600 acre-ft. The voids in the fallback material between the limits of this and the true crater will add considerably to the safety factor. The water trapped in such a crater will be dissipated by evaporation and possibly some seepage (1, Fig. 3).

With the storage capacity provided and the infrequency of thunderstorms at any one location, particularly of the magnitude of the design storm, this design should provide adequate protection.

## COST ESTIMATES

### Conventional Solution

The Santa Fe's most economical conventional construction (although not economically feasible) is the "Tunnel Route." The cost for the 4.34 mi of railroad, including 12,800 ft of double-track tunnel, is estimated at about $14.5 million. Almost $10 million is for tunnel construction.

To provide a basis for comparison of highway costs, a distance of 18.03 mi from divergence to convergence of the highway conventional and nuclear routes was used. The estimate for construction on the conventional route is about $7.2 million.

### Nuclear Solution

The nuclear solution will first involve a cost of about $330,000 for additional preliminary engineering studies and site investigations. About two thirds of this is for exploratory drilling. The next phase will include construction of access roads and exploration and cased emplacement holes at each device location. This work will cost approximately $2.3 million, about one half for the 30-in. emplacement holes.

The nuclear operations costs are estimated at about $1.9 million. These costs include additional pre-shot safety studies, emplacement and firing, shot-time safety and control, construction of facilities necessary for emplacement and detonation and post-shot safety measures. They do not include charges by the Government for the nuclear explosives.

The post-shot construction costs for the railroad are estimated at about $2.9 million. A great portion of these costs is for grading into and out of the channel. The post-shot highway construction costs for the 18.11 mi used for purposes for comparison are about $6.3 million.

### Comparison of Solutions

In comparison, the total cost to the two agencies each on its own conventional alignment and using conventional construction methods will be about $21.8 million, whereas the total estimated cost of the Project Carryall nuclear solution is $13.8 million, an apparent reduction in cost of about $8 million. These figures do not include the charges by the Government for the nuclear explosives.

### Cost of Nuclear Solution if Done Conventionally

Although perhaps not pertinent, it is interesting to note that the cost of excavating a cut at this location by conventional methods and comparable to the proposed nuclear cut would probably cost at least $50 million for the 68 million cu yd of excavation involved.

## GENERAL CONCLUSIONS OF THE JOINT STUDY GROUP

### Technical Feasibility

Based on the results of this study, this project is deemed by the study group to be technically feasible.

1. It is considered possible, based on present data and technology, to excavate with nuclear explosives a cut of the required length (approximately 2 mi), bottom width (approximately 325 ft), and depth (between 100 and 350 ft), involving the removal of 68 million cu yd of material.
2. There are no obvious safety problems that would prohibit its conduct.
3. It is considered reasonable to predict that the cut can be made so that the grade required for the highway and railroad will be established within the limits of ± 5 percent.
4. The engineering characteristics of the resultant cut, such as slope stability, rock size, and compaction, will make it possible to construct a railroad and highway through the cut, using conventional construction techniques without inordinate or extraordinary costs or other measures.
5. Although the excavation technology is not completely established and the devices considered optimum for the project are not presently available, their availability is considered to be a reasonable extrapolation of existing technology and currently available devices.

To minimize the post-shot earthwork and to have the safety problems well defined, three projects currently planned as part of the Plowshare nuclear-excavation program (Buggy, Schooner, and Galley) should be conducted in advance.

The projected time schedule for development of appropriately designed nuclear explosives, the conduct of the prerequisite experiments and the completion of the project are compatible, from a technical viewpoint, with the Interstate Highway completion schedules and the desires of the Santa Fe.

### Scientific Benefits

The execution of Project Carryall will provide much data of vital significance to the development of nuclear excavation technology. Its value as a demonstration of the safety, practicality, and usefulness of nuclear excavation and the interest generated in similar projects will, of course, be of major significance. But there will be many other scientific and engineering benefits of a much more real and lasting nature. These include:

1. Confirmation of the accuracy of prediction techniques for row craters in a new medium through irregular terrain at yields significantly larger than any previous row experience;
2. Data on the immediate and long-range slope and foundation stability of crater slopes;
3. Data on the suitability of crater fallback debris for heavy construction purposes and the accommodation of surface drainage;
4. If fired in two or more detonations, the information on interaction between an existing crater and an intersecting crater; and
5. Additional data on the nature of safety questions associated with rows of nuclear charges.

Such information is essential to the orderly development of nuclear excavation as an engineering tool and its ultimate use as a construction technique, and it will be of significant worth to the Plowshare program.

### Economic Feasibility

As previously mentioned, the cost of the nuclear solution is estimated to be about $8 million less than the conventional solution, exclusive of charges for the nuclear explosives.

This figure, however, is meaningful only for the purpose of demonstrating the economic advantage of the nuclear solution over the cheapest combined conventional solutions. The State's alternate, and conventional, solution is feasible, whereas the Santa Fe's is not. The amount the latter could expend within this area on an economically feasible realignment would be considerably less than the $14.5 million estimated for their 2-mi tunnel plan.

The practical economic feasibility is contingent on the amounts the Santa Fe and the State could economically contribute toward the nuclear explosive costs, the charges the Government would make for the explosives, and the degree of participation by Plowshare in such a project. This may be determined and resolved by pending decisions by the management of the three agencies.

## REFERENCE

1. Circeo, L. J., Jr., "Engineering Properties and Applications of Nuclear Excavations." HRB Highway Res. Record 50, pp. 13-31 (1964).