Use of Waste Materials in Embankment Construction

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The impact of environmental constraints and economic considerations compels the engineer to seek new and novel techniques for using waste materials in embankment construction. This paper describes the use of sanitary landfill and nonbiodegradable waste (discarded tires) and design criteria for incorporating waste material into California highway embankments. Construction guidelines and theoretical considerations are presented. One case history and plans for a test embankment that will be stabilized by tire sidewall mats are described.

The California Department of Transportation, like most other road-building organizations, has in the past placed severe restriction on the incorporation of unsuitable materials into highway embankments. Clearing and grubbing were an important and rigidly adhered to first step in the highway construction process. The burial of logs and stumps was prohibited and, indeed, in some cases, knots and twigs were picked out of embankments as part of the construction process. When sanitary landfills were crossed, the waste was normally stripped to original ground and disposed of before construction of the embankment began.

Recently, environmental restrictions, economics, and concern for visual impact have necessitated construction of highways over marginal to extremely difficult terrain. The options with respect to development of borrow and waste disposal sites have been severely restricted and have thus compounded the problem. Thus, reevaluation of past highway practice with respect to waste or unsuitable materials has become necessary.

This paper discusses the use of two types of waste materials incorporated into embankments constructed along California highways: sanitary landfill waste and nonbiodegradable waste (discarded tires).

Recently several case histories (1, 2), concerning the crossing of sanitary landfills with highway embankments, have appeared in the literature. They describe the construction technique and the results of measures aimed at minimizing postconstruction settlements.

On Calif-73 in Orange County, California DOT is nearing completion of a project in which sanitary landfill waste is incorporated into embankment construction. This project is described as is a test embankment yet to be constructed, in which, it is believed, a systematic incorporation of tire waste will serve to benefit the fill and thus permit steeper than normal side slopes and increase resistance to seismic loading.

SANITARY LANDFILL WASTE

General Design Criteria

No general design criteria are described because the contract specifications are described in the discussion of the case history.

Case History

The sanitary landfill waste project consists primarily of an interchange in Newport Beach, California, near the Irvine campus of the University of California (Figure 1). One segment of the interchange provides ramp access to MacArthur Boulevard, which was relocated to accommodate future full alignment.

The results of a foundation investigation revealed that foundation soils were generally soft and compressible, and this necessitated 2:1 side slopes, stabilizing berms, waiting periods, and controlled rates of loading for embankment construction.

The general pattern of foundation soils consists of alternating strata of compressible clay and fine to coarse sands that appear to be free draining. Figure 2 shows the boring locations and the log of the borings for a portion of the realigned MacArthur Boulevard, including a portion of the sanitary landfill.

As indicated by the borings, a sanitary landfill containing 152 910 m^3 (200 000 yd^3) of refuse occupied a section of the line along which the realigned MacArthur Boulevard and University Drive would be constructed. Construction of this landfill began in 1954 and was completed with 0.6 m (2 ft) of earth cover in 1961.

As the design of the interchange was nearing completion, it became apparent that removal of this huge

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quantity of waste would involve a tremendous expenditure. Construction of embankments over the landfill would subject the roadway to intolerable long-term settlement and compound the problem already present because of the nature of the subgrade soils.

Inquiries by designers with respect to disposal of the waste revealed that the only available option was placement in another sanitary landfill. Since the project was deficient in embankment, the 152 910 m^3 (200 000 yd^3) would have to be replaced by material obtained from outside the project limits and delivered to the site at an estimated cost of \$3.92/m^3 (\$3.00/yd^3). Thus, the potential net savings available by using the waste in embankment construction was estimated at \$900 000. This finding prompted further study of the possibility of using the waste in the embankments. There was little information to draw on, except for recent limited experience in the burial of wood waste in embankments. The specifications ultimately developed by the District Design, Construction, and Transportation Laboratory personnel for this purpose are as follows:

> Those areas shown on the plans as "Refuse Removal Area" are areas of unsuitable material. The Contractor shall excavate the refuse cover and refuse material and construct embankments within the excavated refuse area with material obtained from excavation within the project limits (except excavated refuse material) or borrow.
>
> At the option of the Contractor, excavated refuse material may be used in embankment construction in the areas shown on the plans as "Refuse Embankment Areas."
>
> In addition to the requirements in Section 19-5, "Compaction," and Section 19-6, "Embankment Construction," of the Standard Specifications, the placement of excavated refuse material in embankments shall conform to the following:
>
> 1. Excavated refuse material shall be thoroughly mixed with suitable embankment material at a rate not to exceed 50 percent of the mixture.
> 2. Each layer of the refuse material mixture shall be covered with at least two layers of suitable embankment material.
> 3. No layer of the refuse material mixture shall be placed within four feet of finished grade.
> 4. Rock, portland cement concrete, asphalt concrete, ferrous and nonferrous metals shall not exceed one foot in the vertical dimension when placed in embankments.
> 5. All other material including biodegradable material shall not exceed one-half foot in greatest dimension.

A typical embankment cross section is shown in Figure 3.

The heterogeneous nature of the waste precluded compaction control by conventional means. However, it was reasoned that placement of waste in relatively thin lifts sandwiched between layers of soil would minimize the risk of low densification, since a relatively firm working table would be necessary to achieve the specification compaction requirement in the soils layers.

Refuse embankment construction requirements of the special provisions to the contract include stripping surface materials at refuse embankment sites to an elevation of 1.2 m (4 ft) and constructing embankments to a finished embankment height subject to the following rates of loading:

1. Place 2.7 m (9 ft) of embankment at a rate of 0.41 m (1.33 ft) per week followed by a 60-day waiting period;
2. Construct the embankment to an elevation of 6.7 m (22 ft) at a rate not to exceed 0.41 m (1.33 ft) per week followed by a 60-day waiting period; and
3. From 5.5 m (18 ft) to finished grade elevation, construct at a uniform rate not to exceed 0.9 m (3 ft) per week.

Heave stakes, piezometers, settlement platforms, benchmarks, and inclinometers were installed for construction control. Additional benchmarks were installed at the top of the fills above the settlement platforms at original ground to monitor compression occurring within the fill itself.

Excavation of the landfill exposed a composition of wood, stumps, paper, fibrous wastes, cans, bedsprings, pipe, wire, glass containers, plastics, tires, bricks, and concrete debris. Organic materials encountered were generally in a good state of preservation. Newspapers, dated in the late 1950s, were clear and readable. As had been anticipated, based on the exploration of the fill in late 1970, groundwater was encountered from 4.6 to 6.1 m (15 to 20 ft) below ground surface and was ponded and later pumped into tank trucks for use in the compaction operation. No discharge of groundwater was permitted to enter into San Diego Creek. Leachate was not considered to be a problem, and no program to monitor leachates from the embankment was initiated since the refuse was to be incorporated into embankments several meters above the water table and sandwiched between layers of relatively impermeable soil. The refuse was excavated from the locations shown in Figure 1 and hauled to the embankment with rear-dump trailer and tractor trucks.

The device that ultimately proved most successful for refuse excavation and loading was a hydraulic backhoe. This had several advantages, including a digging action from the top downward into the saturated refuse that penetrated the rags and paper on the initial thrust and filled the bucket. Wet soft areas were worked by reaching out and down; the machine carriage did not enter the area and bog down. The backhoe capacity was found to be approximately 229 m^3 (300 yd^3) of refuse per hour. After the refuse was hauled to the embankment location and dumped, bulldozers spread the material in 15.2-cm-thick (6-in) lifts as shown in Figure 4. At this point, unsuitable pieces including tires (Figure 5) were picked out, stockpiled, and eventually hauled away for disposal at a public dump.

Embankment soils for blending with the refuse were hauled to the site in twin-bottom dump trailers. The soil was spread over the in-place refuse with rubber-tired bulldozers and a motor grader as shown in Figure 6. Mixing was accomplished with either a sheepsfoot roller pulled by bulldozers or a self-propelled sheepsfoot compactor as shown in Figure 4. The compactor spikes penetrated the soil and rubbish and pulled, ripped, and split the rubbish as it was mixed with the soil and compacted. The principal problem was the tendency of the compactor to become plugged with refuse. The sandy soil that was used for the embankment proved to be an asset for the blending operation because of its low cohesion. A similar attempt to mix cohesive or clayey soils with the refuse would have been extremely difficult, if not impossible.

The moisture content of the refuse buried was from dry to saturated. Saturated refuse was spread and allowed to air dry before it was blended with the soil. Specifications were included for odor control of the refuse during handling operations. A commercial deodorant, available for use if obnoxious odors were encountered on this project, was not necessary.

Compaction control of the soil lifts sandwiched between the blended refuse lifts was maintained with nuclear gauges. A relative compaction requirement of 90 percent, according to California Test Method 216, was specified and achieved for the soil portion of the embankment. Compaction control of the blended refuse layers was achieved by visual inspection. Inspectors observed the blending and compaction of the refuse layers and directed the modification of the operation where inadequate compaction or mixing was observed. Exposed layers of the blended refuse were seen as a result of an excavation for a drainage culvert as shown in Figure 7. The blended refuse layers appear across the center of Figure 7, sandwiched between two soil layers. No cavities were observed in the exposed layer. The soil and refuse were moist and thoroughly mixed and could be separated only by using a handpick. The layer appeared to be well compacted.

The sandy soil used for embankment eased the problem of mixing considerably; the success of such an operation with cohesive materials is doubtful. As of June 1976, no significant amount of compression has been detected within the soil-waste fills.

NONBIODEGRADABLE WASTE

General Design Criteria

Engineers have long been aware of the stabilizing effects of inclusions of various materials in earthworks. The first disciplined, and by far the most extensive and successful, application of soil reinforcement was developed by Vidal (3) in the late 1950s. Vidal's system of reinforced earth consists of placing steel reinforcing strips at predetermined intervals within the fill mass for the purpose of providing tensile or cohesive strength in a relatively cohesionless material. For a soil to be satisfactory for reinforced earth construction, Vidal suggests that it be granular and have an angle of internal friction of at least 25 deg so that adequate friction resistance can be developed between the soil and the reinforcing material.

The stabilizing effect of materials with relatively high tensile strength in soil has been observed since ancient times. Increased shear strength with certain types of nonbiodegradable materials was noted during a laboratory study by California DOT (4).

One of the most perplexing solid waste disposal problems involves automobile tires. It has been estimated that approximately 200 million tires are discarded each year in the United States. Air quality legislation precludes burning as a solution. A major problem with respect to burial of tire carcasses in soil is their tendency to eventually work up to the surface. The problem of tire disposal was of sufficient magnitude in California to prompt passage of House Resolution 37 in the 1973 California legislative session, which charged the California DOT to study the problem of abandoned tires and develop possible solutions for their disposal or recycling.

Investigation of the problem of tire disposal revealed that equipment is now commercially available to economically separate tire sidewalls and treads, the latter having been found to be a commercially valuable commodity. The sidewalls alone, having a nearly flat configuration and extremely high tensile strength, are an obvious possibility for soil reinforcement and, if they are placed in strips or mats, could serve to greatly increase the internal stability of an embankment, based on the reinforced earth principle. To go one step further, it was speculated that embankments stabilized in this manner could be constructed at much steeper side slopes than would otherwise be possible and could provide a means of disposal of this troublesome waste product.

To study this possibility further, California DOT Transportation Laboratory conducted an analysis to determine the theoretical effects of tire reinforcement on earthquake resistance of embankments. This analysis assumed tire placement in mats extending for widths of 0.8 of the embankment height at vertical intervals of 1.2 m (4 ft). It was accomplished with the Quad-4 finite element program developed at the University of California, Berkeley. The finite element mesh (Figure 8) consisted of elements representing the reinforcing mat and boundary soil.

The embankment was assumed to have a relative density of 90 percent and a density of 2082 kg/m^3 (130 lb/ft^3). Shear modulus G was assumed to vary with overburden height as shown by the following equation (4):

$$G = K_2(\sigma_o')^{1/2} \qquad (1)$$

where

G = shear modulus in pascals,
K_2 = function of relative density D_r, and
σ_o' = effective overburden stress in pascals.

The foundation soil was also assumed to be sandy and had a relative density of 75 percent and a density of 2082 kg/m^3 (130 lb/ft^3). From equation 1, the K_2 of the 1.5 m (5 ft) of foundation soil is 61. For the composite material, a constant shear modulus of G = 6.37 MPa (133 kips/ft^2) was used, based on the results of tests on rubber tire specimens. A constant damping factor of 25 percent was also used. The embankment was assumed to be 7 m (23 ft) in height with 1½:1 side slopes. The earthquake selected was the California Institute of Technology type C-1 with a maximum acceleration of 0.3 *g*, a period of 0.35 s, and a duration of 12 s applied at the base of 1.5 m (5 ft) of foundation material. This would correspond to an earthquake measuring 7 on the Richter scale at a distance of 24 km (15 miles) from the fault. The results in terms of change or reduction in the dynamic shear stress resulting from reinforcement are shown in Figure 8. Under these conditions, dynamic shear stress would be reduced in the embankment soil by 20 to 62 percent, at an average of about 33 percent. The greatest reduction occurs in the interior; this would indicate that failure, if it did occur, would probably be on the surface. Shear strain would experience a similar trend and would be reduced by about 33 percent in the embankment soil. These values would, of course, vary with side slope, type of soil, earthquake intensity and duration, and fill height. The results of this analysis and the earlier laboratory study of the stabilizing effect of waste led to a decision to construct a prototype test embankment in which tire sidewall mats were used for reinforcement. Federal Highway Administration approval for the instrumentation and analysis portions as a Highway Planning and Research (HPR) project was received on August 8, 1973.

Plans for Embankment

In early spring 1976, a test embankment was suggested by California DOT that, although not ideal from a research standpoint, would definitely be constructed during the 1976 construction season. It is located on Calif-236, about 24 km (15 miles) north of Santa Cruz (Figure 9). The proposal stated that a sidehill fill slipout would be corrected by constructing an embankment approximately 91.5 m long and 15 m high (300 ft long and 50 ft high).

The slide is located on the northwest slope of a narrow, densely forested ridge. This area is underlain by the Rices mudstone member of the San Lorenzo formation, Oligocene Age, and consists of poorly cemented mudstones, siltstone, and sandstone. Bedding planes dip steeply northeastward parallel to the ridge. An investigation of the slide mechanism revealed a depth of unconsolidated and loose slide material and freewater from 18.3 to 21.3 m (60 to 70 ft) below roadway elevation. It was concluded that the primary cause of the slide

Figure 1. Sanitary landfill waste project location map.

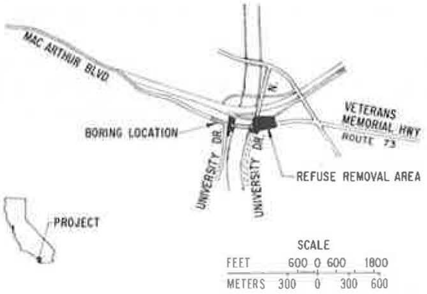


Figure 2. Boring locations and soil profile along portion of realigned MacArthur Boulevard.

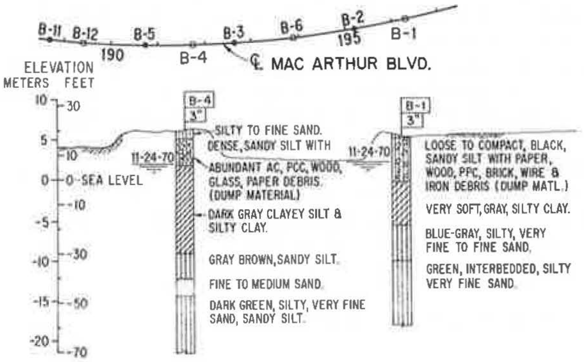


Figure 3. Cross section of engineered refuse fill and substrata.

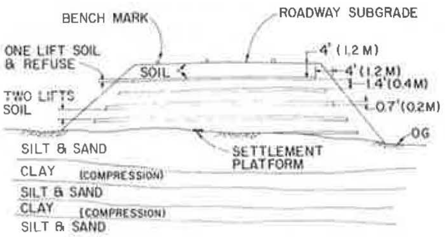


Figure 4. Sheepsfoot compactor processing refuse-soil layer.

Figure 5. Refuse rejected as unsuitable.

Figure 6. Bottom dump delivering load as rubber-tired bulldozer spreads soil over refuse.

Figure 7. Blended refuse layer exposed by 1.5-m-deep trench excavation.

Figure 8. Percentage reduction of maximum dynamic shear stress determined by finite element mesh.

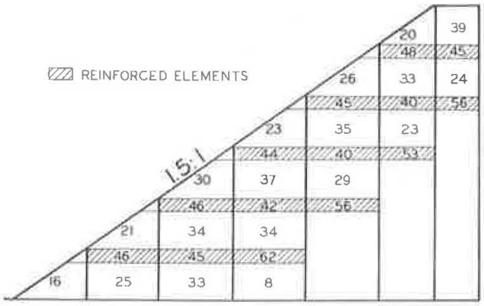


Figure 9. Nonbiodegradable waste project location map.

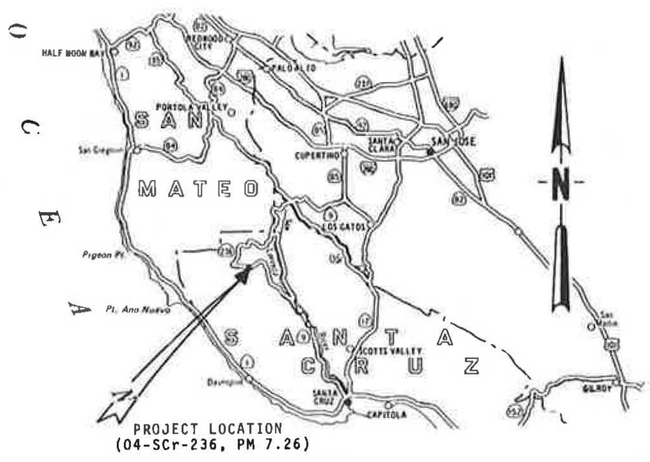


Figure 12. Theoretical peak connector strength versus required strength of 9.5-mm steel bar in cohesive and cohesionless soils for embankment heights to 18 m.

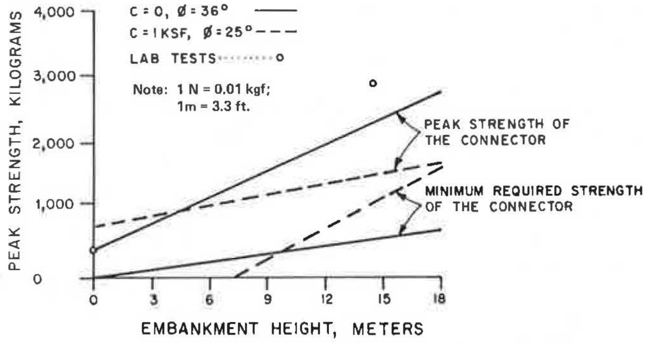


Figure 10. Cross section of tire reinforcement and instrumentation.

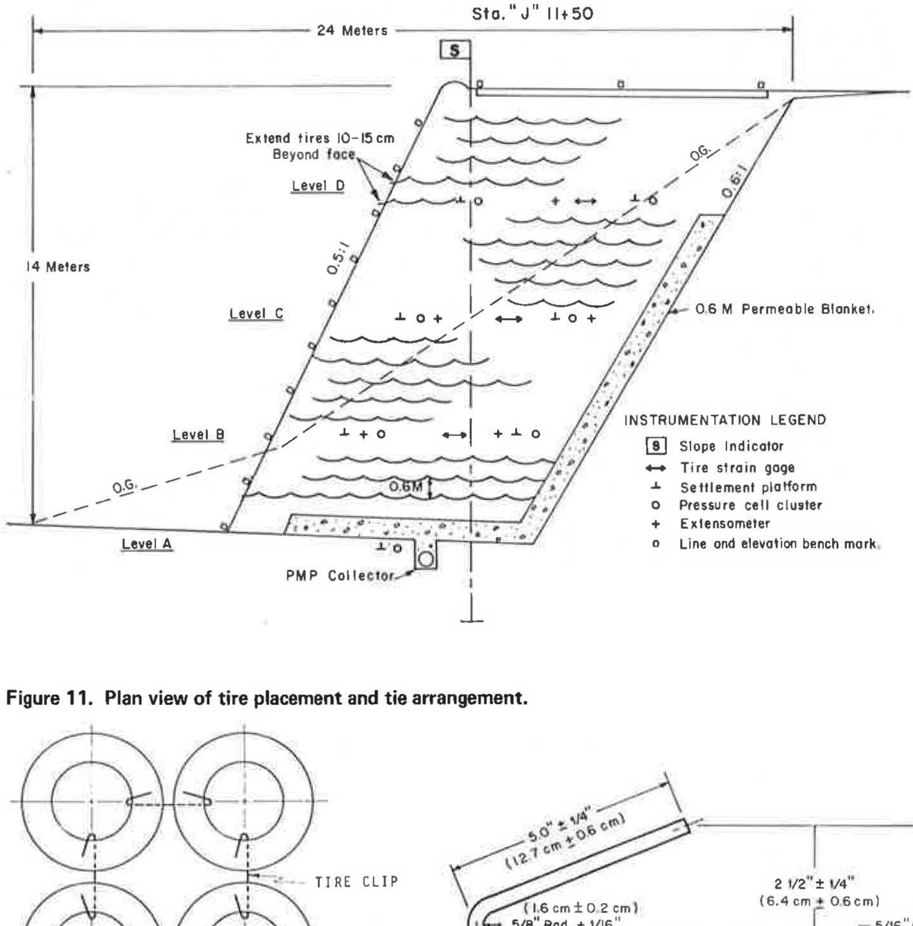
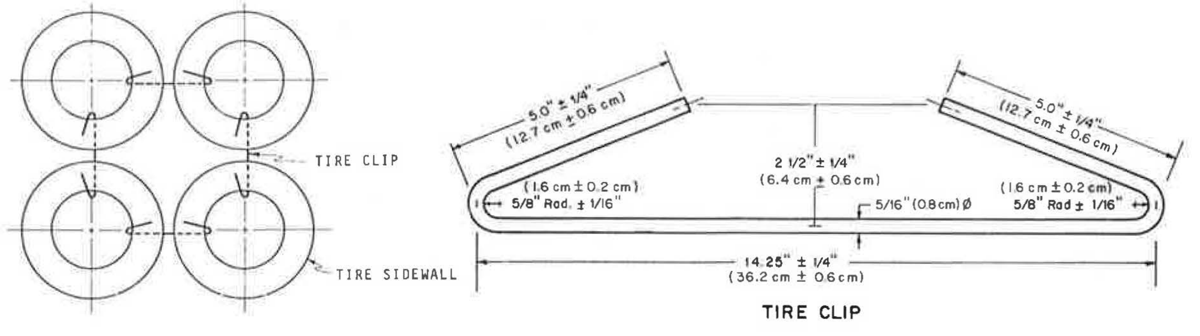


Figure 11. Plan view of tire placement and tie arrangement.



was subsurface water that, over a period of years, had saturated and weakened the earth mass supporting the roadway and ultimately had caused failure. The generally unfavorably bedded fractured planes were also a factor.

The experimental embankment is to be constructed on a side slope of $^1/_2$:1. It is estimated that the steepened slope, made possible by stabilization, will save approximately 68 810 m^3 (90 000 yd^3) of embankment that would have been necessary with the conventional $1^1/_2$:1 side slope because of the sloping nature of the terrain.

The essential elements of the test embankment include removal of the slide debris to well below the apparent slide plane, construction of a positive subsurface drainage system to relieve the cause of initial failure, and extensive instrumentation of the central section to monitor fill behavior (Figure 10). The outer 1.8 m (6 ft) of the embankment will be treated with straw. Seed and mulch will be air blown onto the face of the slope when construction is completed.

The tire sidewall mats will extend 10.2 to 15.2 cm (4 to 6 in) beyond the edge of the embankment to minimize erosion until permanent growth is established. The resulting artificial serrations should serve as energy dissipators for surface runoff. Mat embedment depth will be sufficient so that the reinforced portion of the embankment, if considered as a gravity system, will have sufficient mass to resist overturning and sliding.

In all large direct shear tests of the tire sidewall mats embedded in soil, the critical element was the connector rather than slippage between soil and tire mat or tensile failure of the tire sidewall. Initial consideration was given to the use of heavy (14-gauge), pneumatically fired staples. The results of pull tests using up to four such staples revealed an inconsistent performance, due primarily to the difficulty in obtaining consistently tight staple closure on the bottom side of the mat.

The clip type of connector that ultimately evolved is shown in Figure 11. Pull tests conducted on this type of connector, using 6.4, 7.9, and 9.5-mm-diameter ($^1/_4$, $^5/_{16}$, and $^3/_8$-in) cold rolled steel, revealed that the 9.5-mm-diameter ($^3/_8$-in) clip provided adequate tensile strength; this was true even when the estimated corrosion loss during the design life of the embankment was considered. Figure 12 shows the peak connector tensile strength versus strength required for embankment heights up to 18.3 m (60 ft) for the range of embankment soil shear strength properties anticipated on the project. The results of two actual laboratory tests are superimposed.

In addition to ease of installation, another important advantage of the clip connection is increased rigidity of the mat since the clips will grip the tire sidewall bead.

In April 1976, FHWA was requested to provide demonstration project funds to cover the costs of tire sidewalls, clips, and placement. This request was subsequently approved. Instrumentation analysis of data will be accomplished under the aforementioned ongoing HPR project. Project construction is expected to begin between August 15 and September 1, 1976, and to be completed within 1 month to 6 weeks. Instruments will be monitored for 2 years after construction.

SUMMARY AND CONCLUSIONS

Environmental constraints and economic considerations recently have necessitated a reevaluation of past highway practice with respect to inclusion of waste materials in embankments.

Experience with the Calif-73 project in Orange County thus far has demonstrated that satisfactory embankments can be constructed by using landfill waste. Whether landfill waste should be used must depend on an evaluation of engineering feasibility and aesthetics, based on availability of disposal sites, volume of landfill wastes, waste composition, state of waste decomposition, possible deleterious effect of the use of landfill waste on water quality, nature of embankment soil, and time constraints (effect of waiting periods).

A primary concern is the heterogeneous nature of the material. For obvious reasons, relative compaction cannot be used as a control test. Thus, the engineer must judge and supervise the operation and be prepared to make modifications to the character of the waste. Shear strength and consolidation characteristics, if necessary, must be determined by in situ testing. Instrumentation is of fundamental importance in controlling or modifying the operation.

Laboratory studies and dynamic response analysis have indicated that the systematic inclusion of certain nonbiodegradable wastes (tire sidewalls) could possibly benefit a fill and thus permit steeper side slopes and increase resistance to earthquake loading.

A test embankment to evaluate this premise is now planned for construction on Calif-236 in Santa Cruz County in early autumn 1976. It will be constructed at a $^1/_2$:1 side slope reinforced with tire sidewall mats at 0.6-m (2-ft) intervals. The performance of the completed embankment will be monitored by instrumentation installed during its construction.

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The contents of this report reflect the views of the Transportation Laboratory, which is responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the state of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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