Experimental Tire-Anchored Timber Wall

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The design, construction, and first-year performance of an experimental tire-anchored timber retaining wall constructed with salvaged materials are described. The tire-anchored timber wall is an extension of previous research by the California Department of Transportation in which tire sidewalls were used to reinforce embankments. Two walls were constructed in August 1981 on CA-203 at Mammoth Lakes, California. They consisted of used railroad ties for facing supported by embedded tire sidewall and steel tie-back anchor assemblies. Wall heights varied from 3 to 12 ft with a 1.5:1 sloping backfill. One wall was instrumented to monitor stresses in the anchor bars and horizontal and vertical movements of the face. The walls are performing satisfactorily after one winter season that included an earthquake that measured 5.8 Richter local magnitude. No visual damage or increases in anchor bar stress were sustained or recorded even though ground accelerations at the site were estimated to be between 0.2 and 0.3 *g*. The tire anchor walls were constructed at a bid price of \$22/ft² compared with conventional concrete retaining walls proposed for the same sites, which were estimated at \$50/ft². The performance of these prototype tire-anchored walls has exceeded all expectations. The cost-saving advantages of this system have created considerable interest, and several walls of this type are proposed for rural locations in California.

Recently, many public agencies have been emphasizing recycling or salvaging materials to reduce construction costs and in turn reduce the nation's energy needs. In 1981, the California Department of Transportation (Caltrans) developed a retaining wall system of soil reinforcement that incorporates two waste materials--used automobile tire sidewalls and used railroad ties.

The concept of tire sidewall reinforcement of soil was originally conceived during a Caltrans federally financed research study in 1973. A laboratory phase of that study indicated that the inclusion of certain high-strength, nonbiodegradable materials could increase the strength of soil masses (1). Accordingly, it was proposed to evaluate embankment construction in a field study that would use discarded automobile tire sidewalls as reinforcement.

The concept had merit for several reasons: (a) It provided burial of a nonbiodegradable waste product in a mandatory fill reconstruction project, (b) it provided the beneficial effect of mechanically increasing the embankment's static (and dynamic) stability by reinforcement, and (c) it reduced right-of-way requirements and fill construction costs by permitting steeper than normal fill slopes (2).

This initial experimental project was located on CA-236 in the Santa Cruz Mountains and was completed by Caltrans in 1976 (3). Interconnected layers of tire sidewalls at 2-ft vertical lifts were used to form a 50-ft-high embankment (see Figure 1). The slope ratio was 0.5:1, and the tire sidewalls were individually connected by hanger-shaped rebar.

The facility has performed satisfactorily except for a slipout of approximately 5 percent of the fill during the winter of 1978, due primarily to an inadequate subsurface drainage system after a period of almost unprecedented rainfall. No wall facement was used, and some problems were encountered with soil erosion on the steeper than normal fill slope.

The success of this research led to the development of the tire-anchored retaining wall system described in this paper. The paper covers design, construction, and performance of an experimental wall.

GENERAL DESCRIPTION

The tire-anchored retaining wall concept was developed by Caltrans engineers who recognized that discarded automobile tires can be effectively used for earthwork reinforcement. Impetus for this application was provided by the nonbiodegradable nature and high tensile strength of tire sidewalls plus the success of Caltrans' mechanically stabilized embankments (MSEs) (4).

The tire-anchored system is an extension of the Caltrans MSE concept, which uses bar mats anchored to a wall facement to resist lateral earth pressures. Like the bar mats, the tire-anchored system can develop high traction forces in marginal embankment material by using the cohesion as well as the frictional resistance of the compacted soil.

The tire-anchored system is composed of tire sidewalls (tires cut at the shoulder with the tread portion discarded) gripping a tie-back anchor bar through the restraining action of a cross-arm (see Figure 2). The cross-arm, welded to the tie bar, reacts against the tire bead to provide a positive grip. No other mechanical connection is required. High traction forces are developed as a result of the sidewall's large exposed surface area.

The trial for the tire-anchored design was a road-widening project on CA-203 in Mammoth Lakes, California. The retaining walls were to be constructed from used 7-in by 9-in by 8-ft railroad ties laid horizontally and supported by steel tire anchor bar assemblies fastened to vertical timbers set at 4-ft centers (see Figure 3). The facement material results in an aesthetically pleasing design that blends with the surrounding mountain resort architecture. The construction consisted of two single walls with a total length of approximately 750 ft and a height of 3-12 ft.

Although conventional concrete retaining walls were originally proposed for this project, cost estimates were almost double that of the timber wall, which would also be aesthetically pleasing and more compatible with the environment. The simplicity of the tire-anchored timber wall lent itself to the short construction season at this 8000-ft elevation.

Because a wall of this type had never before been constructed, it was proposed to instrument the highest of the two walls and monitor its performance. This was accomplished through a federally financed research project.

WALL DESIGN

The excavation site for the proposed walls was in glacial material that varied from large boulders to fine silt. Because relatively pervious imported material was planned as backfill behind the walls, no special subsurface drainage features were proposed.

The strength and physical properties of these materials are given below (NP = nonplastic):

Type of Material	Foundation Material	Imported Backfill
Angle of internal friction (%)	44	37 to 45
Cohesion (lb/ft^2)	0	0
Plastic index (%)	NP	NP
pH	6.5-6.9	6.5-6.9
Resistivity (ohm-cm 000s)	13-30	13-30
Sand equivalent	44-71	39
Maximum dry density (lb/ft^3)	130	137

Figure 1. Experimental 50-ft-high tire fill constructed near Santa Cruz, California, in 1976.

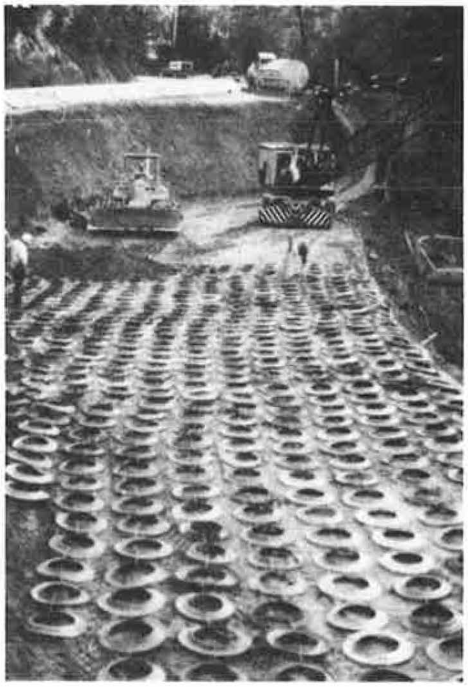
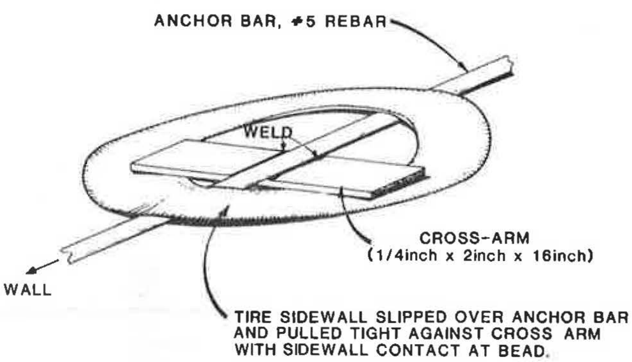


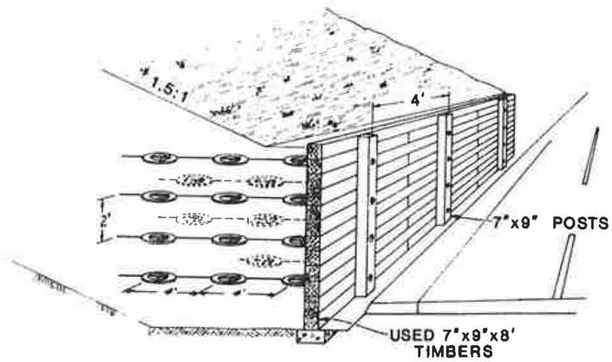
Figure 2. Typical tire-anchor bar assembly showing fastening concept of anchor bar, sidewall, and cross-arm.



The results of the sieve analysis are as follows:

	Percentage Passing by Weight	
Sieve Size	Foundation Material	Imported Backfill
12 in	--	--
6 in	--	100
3 in	--	99
2.5 in	--	97
2 in	85	94
1.5 in	78	86
1 in	73	76
0.75 in	69	68
0.5 in	64	60
0.375 in	60	54
No. 4	49	44
No. 8	40	37
No. 16	31	29
No. 30	25	22
No. 50	19	14
No. 100	13	9
No. 200	9	7
5 μm	--	2
1 μm	--	1

Figure 3. Artist's concept of tire-anchored timber wall.



The walls were designed based on an angle of internal friction of 39° with no cohesion. A soil wet density of 140 lb/ft³ for the backfill and foundation materials was anticipated.

The sloping backfill above the wall for the Rankine active pressure condition called for 0.625-in-diameter steel anchor assemblies. Steel with a 60-ksi yield stress (90-ksi ultimate stress) was used. Sufficient sacrificial steel for corrosion loss through a 50-year design life was provided. Bar diameter was determined for maximum wall height and was maintained constant throughout the fill.

The anchor bar design called for steel cross-arms as shown in Figure 2. The cross-arms are welded to the main anchor bars on 4-ft centers, the first cross-arm 3 ft back from the face. The cross-arms provide a positive connection with the tire sidewalls and require no other mechanical fixture. The front ends of the anchor bars were threaded and extended through the facing for a bolted connection. The anchor assemblies (anchor bar plus cross-arms) were galvanized after fabrication.

The wall facing was to consist of structurally sound used railroad ties with three unmarred sides and adequate creosote treatment to satisfy the design life. The facing members would be placed and erected on a nonreinforced concrete leveling footing. Because the design allowed free outward movement of the facing, there was no fixity at the base. Maximum bar force was estimated to be approximately 5 kip.

Horizontal embedments of 7.5 ft (two tires), 11.5 ft (three tires), and 15.5 ft (four tires) were specified for wall heights up to 6, 8, and 11 ft, respectively. Figure 4 illustrates the instrumentation cross section and plan view of the tire-anchored timber wall.

Laboratory pullout tests on tire anchor assemblies were used to evaluate the internal stability of the system. A typical plot of load versus deformation during pullout is shown in Figure 5. This plot suggests that a single tire assembly embedded in granular soil under 1 ton/ft² of overburden pressure could provide at least 14 kip of ultimate pullout resistance. Although one sidewall per anchor bar would have provided adequate pullout resistance, multiple tires were used in the wall design to provide mechanical reinforcing of the entire compacted embankment. The overall system of four tires provided a safety factor against pullout in excess of 10.

Embedment depth depends primarily on sliding and overturning of the reinforced soil mass system and secondarily on pullout resistance of the anchor bars. For the Mammoth Lakes design, tire embedment was approximately 1.4h, where h is wall height. Although an embedment of 0.8-1.0h is generally satis-

Figure 4. Instrumentation cross section and plan view of tire-anchored wall showing reinforcement and strain gage locations.

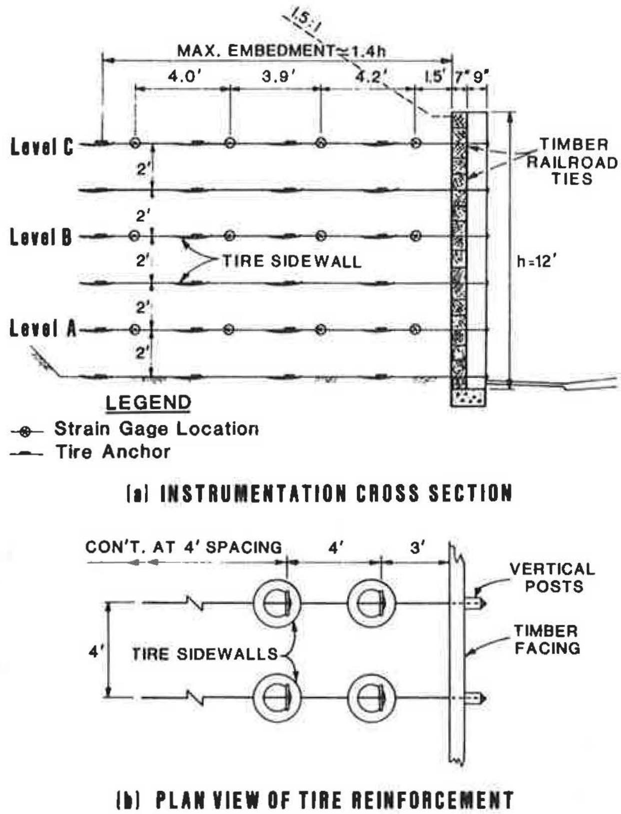


Figure 5. Pullout load versus horizontal displacement for 14-in tire sidewall and 0.5-in-diameter steel anchor bar embedded in decomposed granite.

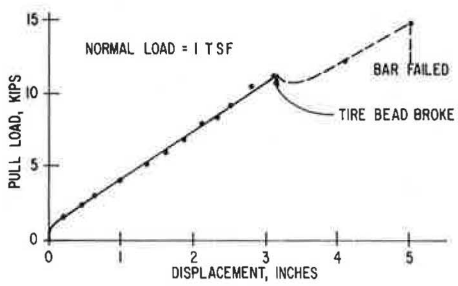
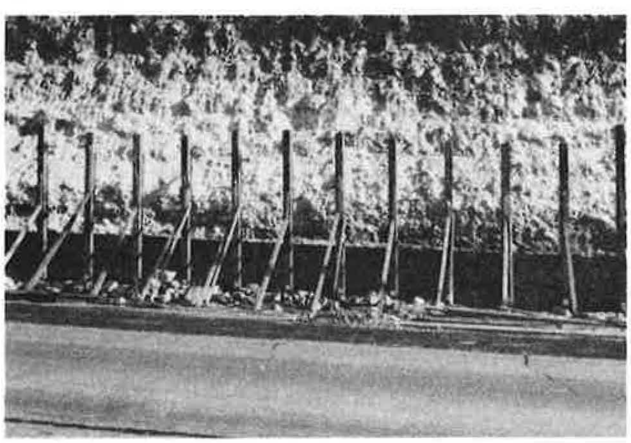


Figure 6. First phase of wall erection.



factory, the steep back slope and untried nature of the system dictated a conservative design. Theoretical external safety factors against overturning and sliding of the wall were approximately 2.8 and 2.3, respectively, based on a triangular Rankine active pressure state. Swedish slip circle analysis of internal wall stability indicated a factor of safety against static failure of 1.70. Based on a lateral earthquake coefficient of 0.2 (maximum credible event), pseudostatic analysis indicated a minimum factor of safety of 1.2.

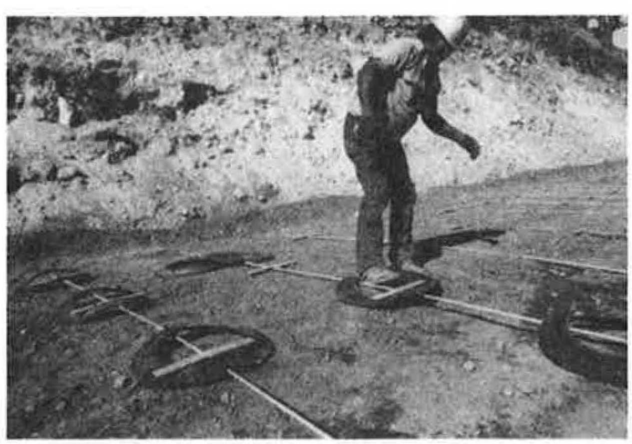
WALL CONSTRUCTION AND COSTS

The project was advertised in March 1981. Bids were opened in April 1981. The successful low bid was $\$22/ft^2$ for the timber wall, which included labor, materials, and equipment for excavation, backfilling, and erection. Wall costs for reinforced concrete, concrete crib, and reinforced earth design were estimated by the state at $\$50$, $\$35$, and $\$30/ft^2$, respectively.

The contractor utilized used railroad ties for the horizontal and vertical members, which were of the relay grade (no splits) and were comparable to new grade stock. Timbers of lesser quality were not allowed. New grade number 1 treated Douglas fir timbers could have been substituted at a cost increase of approximately $\$2/ft^2$ of wall face. Because the vertical posts are the primary supporting

Figure 7. Placement of tire-anchored assemblies.

Figure 8. Backfill operation.



element of the wall, future contracts will require new treated timbers for vertical posts. The 1981 cost for 7-in by 9-in by 8-ft used ties (relay grade) and new ties was approximately $10 and $22.50 each, respectively, delivered. The relay grade of used tie is readily available.

Figure 9. Placement and hand compaction of fill over instrumented tire anchor bar assemblies.

Tire sidewalls were cut from 14- and 15-in used passenger car tires. Tires were cut circumferentially at the shoulder, which separated the tread from the sidewalls. The cost of cutting was about $1/tire. Due to their nonbiodegradable nature, no preservative treatment was necessary. Sidewall widths were specified to be a minimum of 4 in. Thus, a 15-in tire would provide two ±23-in (outside diameter) sidewalls. Tread section disposal was the responsibility of the contractor. Tire treads are commonly used for shoe soles, bumpers on boat moorings, rubbing rails in amusement parks, or as an asphalt additive.

Excavation for the wall began in July 1981. The concrete leveling footing was cast on July 31, 1981. After several delays, major wall erection began in late August and was completed in one week. Construction consisted of placing the vertical members directly on the footing and bracing them in a vertical position on 4-ft centers (see Figure 6).

The horizontal members were placed on top of the footing and were toe-nailed to one another and to the vertical members with 40d nails. The vertical members were braced and held in position prior to backfilling and placement of the tire anchor assemblies.

Holes were drilled through the vertical members

Figure 10. Close-up view of completed wall.

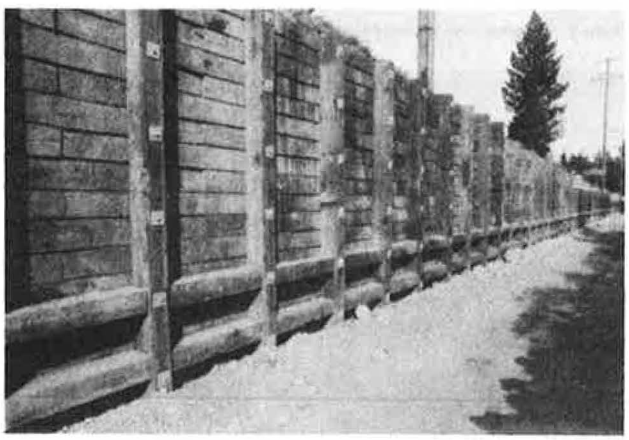


Figure 11. View of completed tire-anchored timber wall and erosion protection on slope.

Figure 12. Wall progress and average anchor bar stress (and force) near wall face versus time.

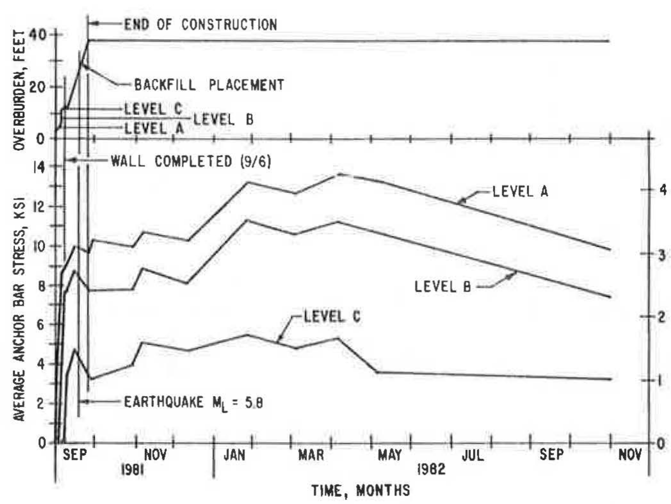


Figure 13. Average maximum anchor bar stress (and force) versus distance behind wall.

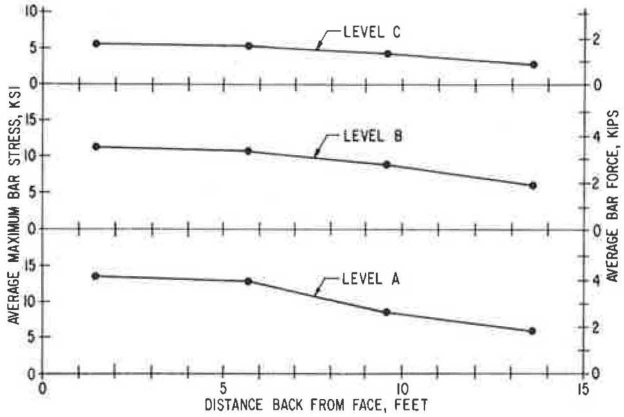
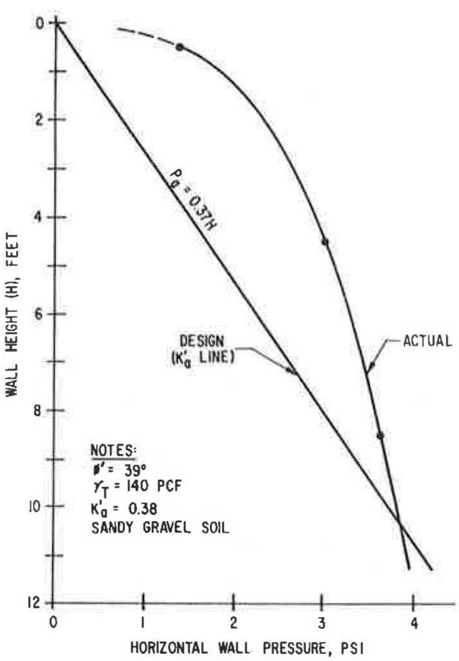


Figure 14. Comparison of actual and theoretical (active case) wall pressure distribution versus wall height.



on 2-ft vertical centers to accommodate the anchor bars. The anchor assemblies were placed on the backfill as it reached each reinforcement level. The threaded ends were inserted through the facing, and a 4x4x0.25-in galvanized steel plate washer and nut was attached. The tire sidewalls were hooked over the cross-arms and pulled tight against it (see Figure 7). Backfill was placed over the anchor assemblies as shown in Figure 8. The rods were then tightened to a specified torque after placement and compaction of 2 ft of soil over each reinforcing level.

The instrumented anchor assemblies were covered with hand-compacted fill (see Figure 9) before equipment was allowed to pass over the instrumentation area. Figure 10 shows a close-up view of the completed wall. A distant view is shown in Figure 11. Brush layering and straw were placed on the slope above the wall to prevent erosion.

The wall was completed during the week of September 5, 1981, and the sloping backfill was completed two weeks later.

INSTRUMENTATION

Epoxy-bonded SR-4 full bridge strain gages were installed and calibrated in the laboratory for six steel anchor bar assemblies placed within the highest wall section. These strain-gaged steel anchor assemblies were installed at three selected elevations (levels A, B, and C) on two vertical cross sections 8 ft apart (Figure 4). Reference monuments were also established on top of the wall, at the base, and near midheight on 50-ft intervals for a distance of 100 ft on each side of the instrumentation station. Instrumentation was monitored, and observations of visual condition were made at various phases of construction.

WALL PERFORMANCE

Visual observations and strain gage measurements were obtained during construction from August through September 1981 and will continue through the spring of 1984. Horizontal and vertical deformations of the timber facing have also been recorded from surveys taken on reference points on the wall. The results of instrumentation monitoring through October 1982 are presented here.

The performance of the tire-anchored timber walls has been satisfactory to date. The winter of 1981-1982 was one of the wettest years on record: Snowfall was 50 percent above normal.

The Mammoth Lakes area is also very active seismically. Several small to moderate earthquakes have occurred since construction. The largest (Richter magnitude $M_L = 5.8$) occurred in September 1981 after completion of the walls and generated site-estimated ground accelerations between 0.2 and 0.3 *g*. No increases in anchor bar stresses were determined from strain gage monitoring, and there was no visual evidence of damage.

Figure 12 presents the time history of wall progress and development of the average anchor bar stress nearest the wall face for the three instrumentation levels for both stations. The highest stresses were recorded in level A at the lower portion of the wall. It should be noted that the calculated stresses before and after the earthquake in late September 1981 indicate no stress increases. There was an increase in anchor bar stresses during the winter of 1981-1982 as the backfill approached full saturation. A relaxation of these stresses occurred during the summer of 1982.

Figure 13 shows the average maximum anchor bar stresses versus distance behind the wall. The highest average stress was calculated at the first gage point 1.50 ft behind the wall face.

Figure 14 shows horizontal wall pressures for both actual and theoretical design conditions. The actual field pressures were calculated from average anchor bar strain readings nearest the wall face. These data indicate that the 1.5:1 sloping backfill, composed of sandy gravel, developed a somewhat uniform pressure distribution for the lower two-thirds of the wall at the peak value of P_a and a triangular distribution for the upper one-third of the wall.

The calculated actual pressure distribution is shown to be in excess of the theoretical triangular pressure. However, the anchor bar design is conservative since it is based on maximum active pressure for full wall height.

Survey monuments monitored to date suggest that vertical movement has been insignificant. However, a total of 0.5 in of lateral movement has been recorded at the instrumentation station following construction. This magnitude of movement is also insignificant and well within the original design assumptions, which assumed a maximum lateral movement of 1 in.

CONCLUSIONS

1. The tire-anchored timber wall concept provides a cost-effective and aesthetically pleasing alternative to conventional retaining wall construction.

2. This experimental wall demonstrated that salvaged materials--i.e., used automobile tires and railroad ties--can be satisfactorily incorporated in wall construction.

3. The wall performed according to all expectations and satisfied its design requirements. In addition, wall construction proved to be simple and rapid.

4. The wall maintained its integrity during a moderate earthquake of $M_L = 5.8$, which produced an estimated maximum bedrock acceleration at the site of 0.2-0.3 *g*.

5. Measured wall pressures for the upper two-thirds of the wall were significantly greater than estimated for design using active earth pressure theory.

REFERENCES

1. J.B. Hannon and R.A. Forsyth. Fill Stabilization Using Non-Biodegradable Waste Products: Phase I. Caltrans Laboratory, Sacramento, CA, Interim Rept., Aug. 1973.
2. R.A. Forsyth and J.P. Egan, Jr. Use of Waste Materials in Embankment Construction. TRB, Transportation Research Record 593, 1976, pp. 3-8.
3. W.S. Yee. Fill Stabilization Using Non-Biodegradable Waste Products: Phase II. Caltrans Laboratory, Sacramento, CA, Final Rept. FHWA/CA/TL-79/22, Nov. 1979.
4. J.C. Chang, J.B. Hannon, and R.A. Forsyth. Field Performance of Earthwork Reinforcement. Caltrans Laboratory, Sacramento, CA, Rept. CA/TL-81/106, 1981.

Simplified Rational Pavement Design Procedure for Low-Volume Roads

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Computerized pavement-management systems are excellent tools for designing and managing road pavements. However, in some instances, it is necessary to do pavement design analysis with a limited amount of time, resources, and input information. For this reason, a simplified pavement design procedure has been developed. This simplified procedure uses subgrade strain to predict applications to failure by using the performance concepts of the present serviceability index. For aggregate-surfaced roads, additional design criteria are rutting and aggregate loss. The designer has the capability to consider seasonal variation of pavement materials by characterizing the materials with the resilient modulus. Sample problems are given for an aggregate-surfaced and a bituminous-surfaced road. It is felt that this design method can be particularly useful to engineers in developing countries, where resource constraints and practicality may prevent the use of more complicated procedures.

During the past several years, a new pavement design procedure has been developed for the U.S. Forest Service through a cooperative agreement with the University of Texas at Austin. This new procedure is incorporated in a comprehensive and versatile computer program called the Pavement Design and Management System (PDMS) (1). This pavement-management system is an excellent tool for designing and analyzing pavement design and rehabilitation strategies. However, in some instances, it is necessary to do pavement design analysis with a limited amount of time, resources, and input information. For this reason, a simplified pavement design procedure was developed that can be used manually and does not require the use of a computer.

This simplified procedure is termed "rational" because it uses mechanistic pavement response parameters to predict pavement performance. This type of rational design algorithm is very useful when an attempt is made to use a design procedure in a variety of applications and is more quantitative than using subjective design variables, such as soil-support factors, material strength coefficients, and regional climate factors.

This paper presents the simplified rational pavement design procedure. It is felt that this method can be useful in many applications of pavement design, particularly to engineers in developing countries, where resource constraints and practicality may prevent the use of more complicated procedures. A short background of the development of the method is followed by the performance equations and instructions on using the design procedure. Sample problems are given for an aggregate-surfaced and a bituminous-surfaced road.

BACKGROUND

The basic algorithm used in the simplified design procedure was developed by correlating pavement performance with calculated values of subgrade compressive strain. This was accomplished through the use of linear elastic-layer theory and performance data from the American Association of State Highway Officials (AASHO) Road Test (2). The resulting equation predicts the number of axle applications of any load X necessary to reduce the pavement condition to a terminal level of the present serviceability index (PSI):

$$\log_{10} N_x = 2.151\,22 - 597.662\,(\epsilon_{SG}) - 1.329\,67\,(\log_{10} \epsilon_{SG}) + \log_{10}\,[(PSI_i - TSI)/(4.2 - 1.5)]^{1/2} \quad (1)$$

where

$\log_{10} N_x$ = $\log_{10}$ of allowable applications of any axle load X,
ϵ_{SG} = subgrade compressive strain due to axle load X,
PSI_i = initial PSI of road, and
TSI = terminal serviceability index, or failure level of PSI.