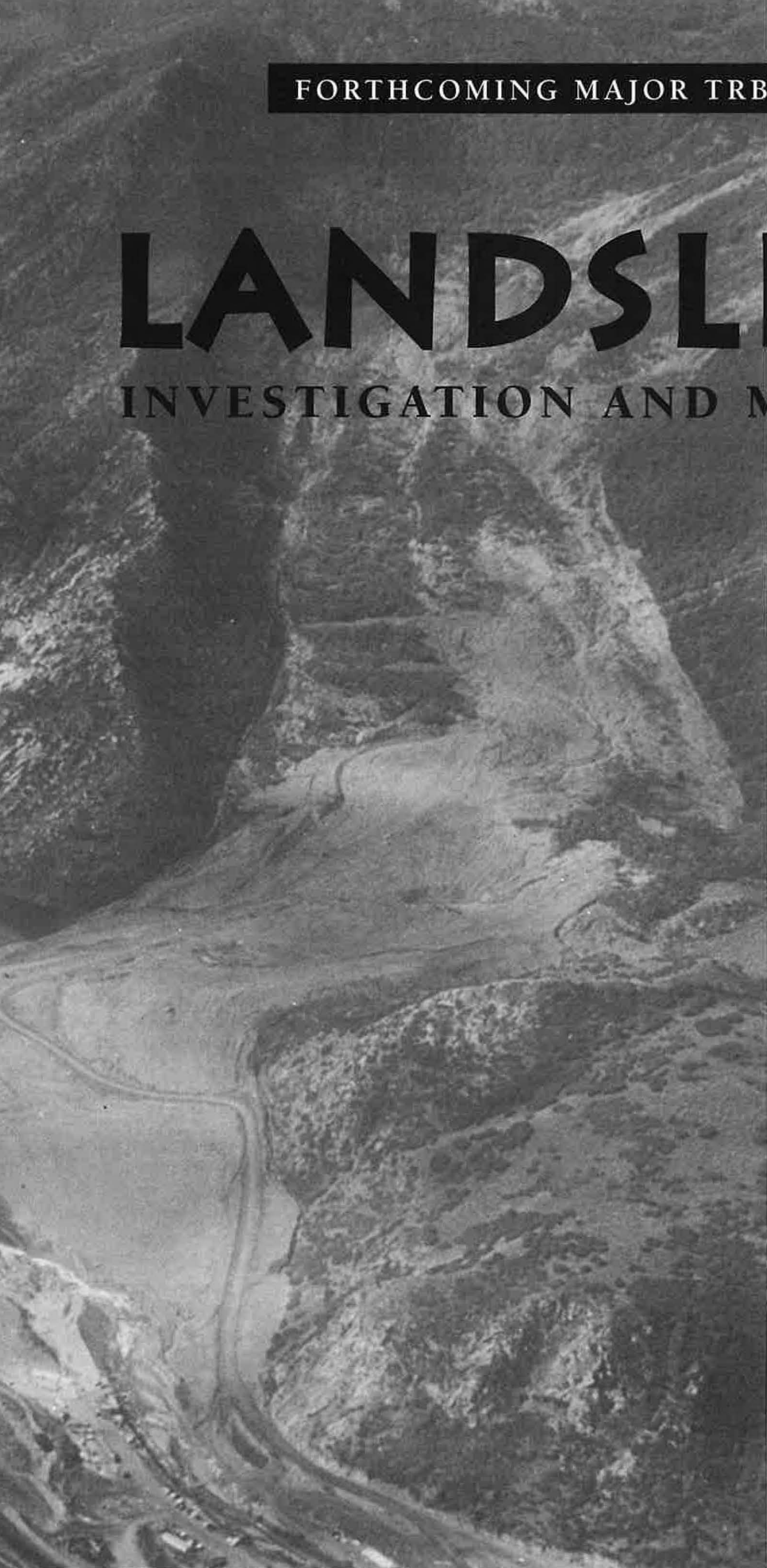
FORTHCOMING MAJOR TRB REPORT

LANDSLIDES

INVESTIGATION AND MITIGATION



A. Keith Turner, Robert L. Schuster, and G. P. Jayaprakash

Landslides: Investigation and Mitigation will be a new and greatly enlarged edition of the two previous Transportation Research Board special reports on landslides published in 1958 and 1978. These reports were widely used in the geotechnical engineering community as comprehensive, practical sources of information on landslides and what to do about them. Among the most successful of TRB publications, they enjoyed wide international appeal and were translated into several languages. The new report, prepared by experts from the United States, Canada, and The Netherlands, will have an even broader international scope. Several authors are involved in international landslide coordination programs; thus this report has been designed to reinforce international efforts.

The publication of *Landslides: Investigation and Mitigation* represents more than 3 years of effort by the 15-member TRB Study Committee on Landslides:

A. Keith Turner is Professor of Geological Engineering at the Colorado School of Mines and Chairman of the TRB Study Committee on Landslides: Analysis and Control. Robert L. Schuster is Geologist and Civil Engineer at the U.S. Geological Survey and a member of the TRB Study Committee on Landslides: Analysis and Control. G. P. Jayaprakash is Engineer of Soils, Geology, and Foundations, TRB.

Analysis and Control. The study committee was charged with reviewing the current state of the art in landslide investigations and producing a new text that incorporated the latest advances in a manner useful to transportation engineers. The new report will contain 25 chapters, 16 more than the 1978 edition.

Many advances in the way landslides are investigated and mitigated have been made in the years since the last edition was published. Chief among these advances are the advent of the personal computer, the availability of new geosynthetic products, and a better understanding of the behavior of earth materials. Personal computers have allowed numerical stability analysis methods to become commonplace; the use of geosynthetics presents options for better and more economical mitigation procedures; and the improved methods for field investigations, coupled with a better understanding of landslide processes, supply better data and concepts to the landslide analysis process.

Landslide Costs

In many countries, socioeconomic losses caused by landslides are great and apparently are growing as human development expands into unstable hillslope areas under the pressures of increasing populations. Damage to and destruction of transportation facilities—highways, railways, canals, and pipelines—account for a significant portion of these losses. The nation most severely affected by landslides is Japan, which suffers total (direct plus indirect) landslide losses of approximately $4 billion annually. In the United States, Italy, and India, total annual economic losses due to landslides have been estimated at $1 billion to $2 billion. Many other countries have lesser, but major, annual losses as a result of landslides.

Transportation Facilities in the United States

Total annual costs of landslides for transportation systems in the United States are difficult to determine because of the difficulty in defining the following factors: (a) costs of smaller slides that are routinely corrected by maintenance forces, (b) costs of slides on non–Federal-aid public highways and roads, (c) costs of slides on privately owned transportation routes, such as railroads, and (d) indirect costs that are related to landslide damage, such as traffic disruptions and delays, inconvenience to travelers and shippers, and costs of analysis and prevention of landslides. In spite of these handicaps, attempts were made during the 1970s to estimate annual landslide losses to the U.S. highway system. Chassie and Goughnour (*1,2*) reported on a survey by the Federal Highway Administration (FHWA) that indicated that approximately $50 million a year (1990 equivalent: $115 million) was spent to repair landslides on the federally financed portion of the national highway system. This system includes federal and state highways, but does not include most county and city roads and streets, private roads and streets, or roads built by other federal agencies, such as the U.S. Department of Agriculture Forest Service, the Bureau of Land Management, or the National Park Service. If indirect costs, costs to nonfederal highways, and the factors noted previously were added, Chassie and Goughnour (2) estimated that $100 million (1990 equivalent: $230 million) was a conservative estimate of the annual landslide damage to highways and roads in the United States in the 1970s.

The 1976 FHWA survey of landslide costs for U.S. highways has been duplicated by Walkinshaw (3), who obtained repair and maintenance costs for landslide damage to 1.3 million km (800,000 mi) of state highways for the 5-year period from 1986 to 1990. Walkinshaw found that the total annual costs of contract landslide repairs on state highways for this period was $65.4 million (Figure 1) and annual landslide maintenance costs (repairs by highway department maintenance forces) were reported as $41.4 million, for a total annual direct cost of nearly $107 million, a figure nearly equal to the 1990 equivalent of $115 million that Chassie and Goughnour (2) found for annual repair and maintenance costs in the 1970s. Thus direct landslide costs to highways have remained nearly constant (when noted in 1990 dollars) in spite of the near-completion of the Interstate highway construction program and drier-than-normal weather in the western United States during the 1986 to 1990 survey period.

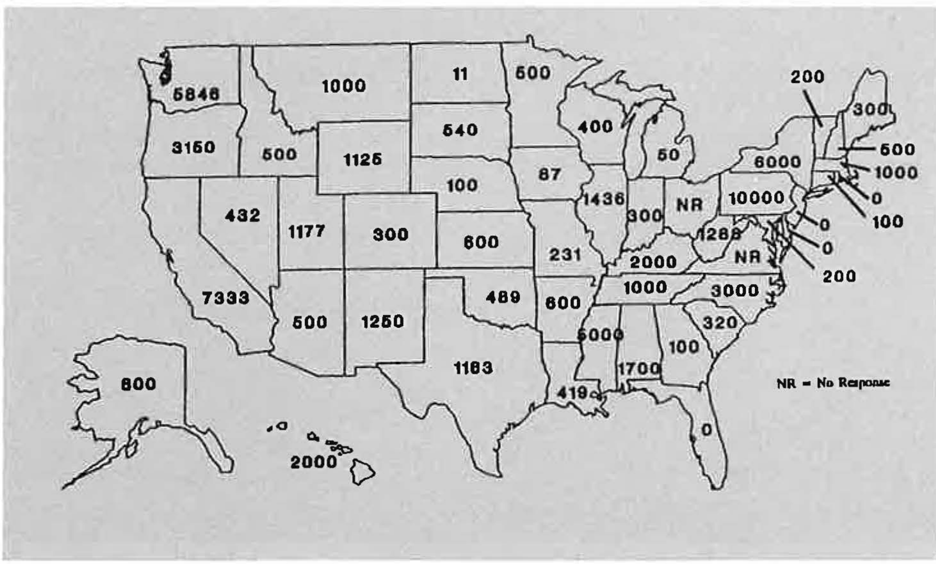


FIGURE 1 Average annual costs (in $1,000s) of contracted landslide repairs on U.S. state highway system from 1986 to 1990 (3).

It should be remembered that the cost figures presented by Chassie and Goughnour (2) and Walkinshaw (3) do not represent total landslide costs, either direct or indirect, for the U.S. highway system. One deficiency of these surveys is that the state and federal highways for which the surveys were conducted represent only about 20 percent of the 6,239,000 km (3,876,000 mi) in the entire U.S. highway and road system. However, this 20 percent probably is subject to the major part of landslide costs because it has been constructed to higher standards (i.e., larger cuts and fills were used) than the rest of the system.

Another deficiency in these surveys is that most state departments of transportation (DOTs) do not maintain satisfactory inventories of their highway landslide maintenance costs. Several states that have kept good maintenance records (particularly Massachusetts, West Virginia, Kentucky, Missouri, Texas, Colorado, and California) have found that the maintenance costs for landslides have exceeded their contract repair costs (3). California reported the highest annual costs of all states for landslide maintenance—more than $15 million per year—even during 5 years of well-below-normal precipitation.

Such landslide cost surveys have not attempted to determine indirect costs of landslides. A cost item that is often large but extremely difficult to determine accurately is the indirect cost of loss of business in communities in which commerce is hindered by the closure of transportation routes as a result of landslides. An example of the magnitude of such indirect costs in relationship to direct actual repair costs was provided by the 1983 landslide closure of U.S. Highway 50 by landslides both west (in California) and east (in Nevada) of South Lake Tahoe. The total cost of repairs to the heavily traveled highway was $3.6 million (1990 equivalent: $4.7 million) (3), but the estimated economic loss to the area due to 2½ months of access disruption and resulting loss of tourist revenues was $70 million (1990 equivalent: $92 million) (4), nearly 20 times as large as the direct expenditures for repair.

There is no definite information on landslide losses by U.S. railroads because nearly all U.S. railroads are private corporations that do not normally release such data. However, some estimates suggest that direct losses to railroads from landslides in the Rocky Mountain states from 1982 to 1985, in which precipitation was much greater than normal, exceeded

FIGURE 2 Aerial view of April 1983 Thistle debris slide, Utah. Photograph from September 1983 shows Thistle Lake, which was impounded by the landslide, the realignment of the Denver and Rio Grande Western Railroad *(lower center)*, and the large cut for rerouting U.S. Highway 6/50 *(extreme lower left)*.

$100 million (1990 equivalent: $120 million). During periods of normal precipitation, landslide losses to U.S. railroads are much lower than they were during this period. An economic impact analysis by the University of Utah (*5*) noted that the largest single loss due to the 1983 Thistle, Utah, landslide (Figure 2) was $81 million (1990 equivalent: $107 million) in revenue lost by the Denver and Rio Grande Western Railroad because of temporary closure of its main line. An example of the effects of landslides on railway operations is shown in Figure 3.

FIGURE 3 Landslide that resulted in derailment of California Zephyr passenger train near Granby, Colorado, in April 1985. Landslide began as an earth slide through the base of the railway embankment *(middle background)* and rapidly moved some 70 m (200 ft) as a debris flow, partially damming Fraser River *(foreground)*.

Panama Canal

The many major slope failures that occurred during construction of the 12-km- (7-mi-) long Gaillard Cut in the Continental Divide segment of the Panama Canal (*6*) constituted one of the world's most extreme cases of damage to a transportation system (Figure 4). Slope failures not only severely disrupted construction, delaying completion of the canal by nearly 2 years, but also caused closing of the canal on seven different occasions after it was opened to traffic in 1914. As noted by MacDonald (*7*), "The confidence of the American people and its Congress was shaken by the delay in achieving continuous service." Although detailed costs of damages caused by Panama Canal landslides from construction to the present are not available, the following data published by the Panama Canal Company indicate the economic severity of the effects of the slope failures (*7*):

- During construction, excavation was disrupted for days and weeks at a time because landslides blocked railroad tracks;
- Steam shovels, locomotives, drilling equipment, railway cars, and other equipment was destroyed during construction (see Figure 4);
- Construction costs were millions of dollars higher than they would have been had the landslides not occurred;
- A total of 57 million m^3 (74 million yd^3) of landslide material was removed from the canal from the beginning of construction to 1940; and
- Many millions of dollars in shipping tolls was lost by delay in opening the canal and by periods of closure due to landslides.

Although landslides have not closed the canal since 1920, they still threaten navigation and pose a continuing and expensive maintenance problem for the Panama Canal Commission, a binational agency representing the Republic of Panama and the United States. A 4.6 million m^3 (6 million yd^3) reactivation of the Cucaracha Landslide (see Figure 5) nearly closed the canal in 1986 (*8*).

PANAMA CANAL COMMISSION

FIGURE 4 Cucaracha Landslide in Gaillard Cut, Panama Canal, August 1912. Note railroad tracks and cars destroyed by this 230,000 m^3 (300,000 yd^3) slump.

PANAMA CANAL COMMISSION

FIGURE 5 October 1986 reactivation of Cucaracha Landslide in Gaillard Cut, Panama Canal. Landslide extended nearly across the canal, but much of the toe had been removed by dredges by the time photograph was taken.

The original width of the channel in the Gaillard Cut was 91 m (300 ft); by 1970 it had been widened to 152 m (500 ft). By the mid-1980s the increase in large-beam ships proved to be an obstacle to navigation through the cut. Thus in May 1991 the Panama Canal Commission implemented a widening program: the channel is being widened to 192 m (630 ft) in the straight portions of the cut and to 213 to 223 m (700 to 730 ft) on curves (*9*). Approximately 27 million m^3 (35 million yd^3) of material will be excavated, which could result in increased slope-failure hazards. To reduce the risk, slopes are being geotechnically designed and drainage systems installed to alleviate the rainfall-induced pore pressures that cause slopes to fail.

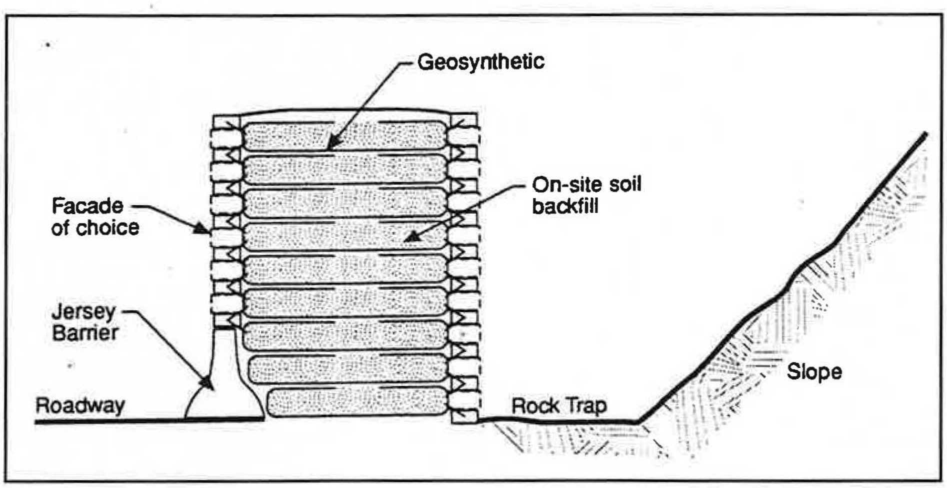


FIGURE 6 Rockfall barrier constructed with soil wrapped in geofabric reinforcement and timber protective facade (*10*).

Rockfalls

Rockfalls represent a slope stability hazard on a smaller scale. However, this hazard has increasingly become of concern in many countries, particularly as road traffic volumes have increased in many mountainous areas. In the United States, a number of state DOTs have shared experiences over the past several years in evaluating new methods for the quantification of rockfall zones, in designing and applying hazard rating systems to direct resources to the most critical slope areas, and in working with manufacturers and research teams in fabricating and testing rockfall protection systems. These activities have involved a variety of formal and informal federal and state cooperative efforts. New lower-cost solutions, frequently involving innovative applications of recycled materials, have been developed at several locations. Examples include geofabric-soil barriers (Figure 6) and rockfall attenuators constructed of old automobile tires (Figure 7), which have been tested by Colorado DOT.

Focus of New Report

The Transportation Research Board special report *Landslides: Investigation and Mitigation* will target a diverse audience. Anticipated readers include transportation engineers responsible for landslide investigations throughout the world, university students studying landslides, and researchers desiring a definitive reference for landslide investigation and mitigation procedures. The report will therefore contain comprehensive, practical discussions of field investigations, laboratory testing, and stability analysis procedures and technologies; comprehensive references to the literature; and discussions of case studies, state-of-the-art techniques, and research directions.

Five major sections will comprise the report. The first section will introduce the issues of socioeconomic impacts of landslides, the classification of landslides, triggering mechanisms, hazard reduction, and risk assessment. The next three will progressively describe the theoretical

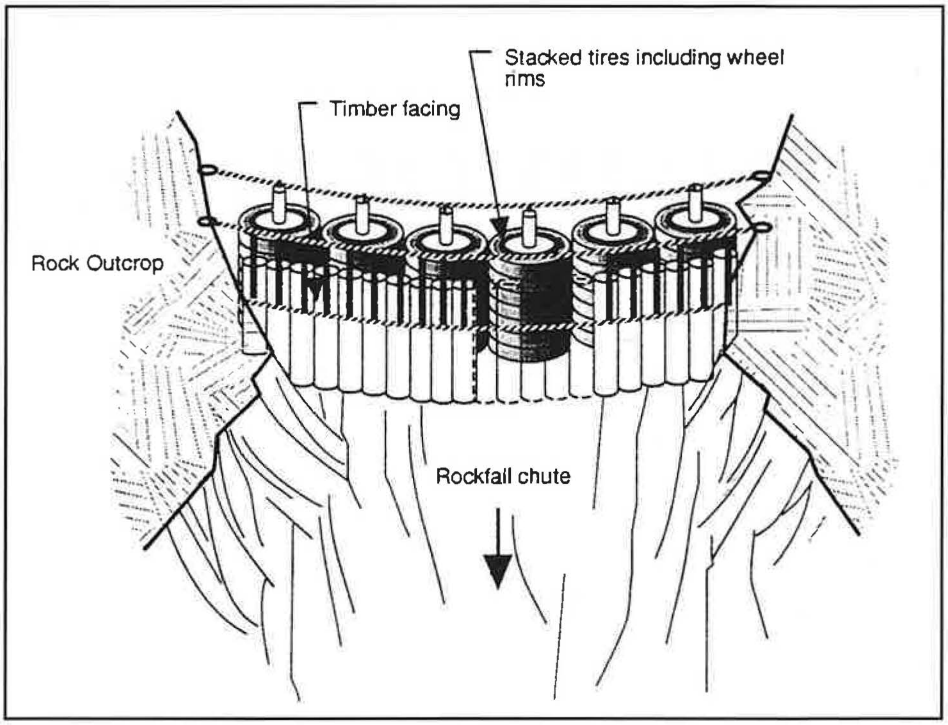


FIGURE 7 Rockfall attenuator constructed of old automobile tires and placed in a rockfall chute (*10*).

basis and procedures for field investigations, strength and stability analysis, and mitigation. The most appropriate methods for both soil and rock materials will be explained and compared in detail. The final section of the report will represent a major addition: the issues and concerns of landslide investigations in specific environmental or geotechnical conditions will be described in seven chapters. Tropical and residual soils, colluvium and talus, shales and degradable materials, hydraulic tailings, loess, soft sensitive clays, and permafrost will be discussed.

Publication of *Landslides: Investigation and Mitigation* is planned for late 1994. For ordering information contact the TRB Business Office, 2101 Constitution Avenue, N.W., Washington, D.C. 20418 (telephone 202-334-3214).

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