Landslide Correction Costs on U.S. State Highway Systems

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The results of a survey made to estimate the cost of landslide damage to the U.S. state highway system in the 5-year period from 1986 to 1990 are presented. The annual contract repair costs are compared with a similar survey prepared in 1976. Maintenance costs for landslide cleanup or repairs were also obtained from about half of the states. The average yearly cost of all contracts awarded by state highway departments during the 5-year period amounted to $68.5 million. Another $37.4 million per year was identified as maintenance costs. There is significant evidence that these costs are only a fraction of the total annual costs of landslides to the state highway network.

This study was prompted by members of a Transportation Research Board Task Force updating *Special Report 176, Landslides: Analysis and Control* (*1*). In 1976, Chassie and Goughnour (*2*), of the Federal Highway Administration (FHWA), reported that $50 million was spent annually to correct landslides on the Federal-aid system. At that time, the Interstate highway system was in full construction and several regions were experiencing large costs because of the lack of adequate preliminary geotechnical investigation and analysis. Some of these problems developed during construction, but others took many years to manifest themselves. The improper placement of degradable shales in large embankments (*3,4*) was one of these problems. Research to properly identify this material and to develop test procedures and implement them in several states cost around $1 million.

Since the FHWA survey was limited to Federal-aid routes under state control, Chassie and Goughnour further projected the average annual cost to be around $100 million for all state highway systems. That survey prompted reviews of the level of geotechnical engineering practiced in each state highway department. Those reviews continue to be updated periodically (*5*) and the results give direction to FHWA's geotechnical research program and the development of training courses through the National Highway Institute.

Once the Interstate Highway System was essentially complete, it was of interest to determine the magnitude of landslide correction across the country. To accomplish this, a one-page survey (see Figure 1) was sent to each state and to three Federal Lands Highway Divisions (FLHD) of FHWA asking for representative costs of landslide corrections during the past 5 years. The FLHD offices administer projects on federal lands such as national parks and forests within each state.

The 5-yr period was short and in certain parts of the country may not be representative of the long-term (20 to 30 years) problem. It was deemed important, however, to get a response from as many states as possible, as a lengthy survey that required an in-depth review of past records would have severely reduced the returns. This philosophy appears to have been successful; only two states did not respond and, significantly, only four states indicated that they had no identifiable landslide costs for the period.

Even though the response was excellent, it must be recognized that the survey was directed principally at obtaining costs on highways under state control. According to FHWA (*6*), this represents 803,400 mi (1,292,900 km) or only 20.7 percent of the 3,876,500 mi (6,238,400 km) of roadways under public agency jurisdiction in the United States.

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SURVEY RESULTS

A summary of the responses to the survey is presented in Table 1. This survey attempted to get representative costs for two types of repairs:

1. Those repairs sufficiently large to require each agency to contract the work, and
2. The landslide repair costs performed by maintenance.

For the second category, only 23 of the 50 states were able to provide some data. Although these data are not as complete, they are very revealing and will be discussed later.

Contract Costs

The average annual contract value of landslide repair is shown in Column 1 of Table 1 and graphically shown on a map of the United States in Figure 2. Column 2 of Table 1 identifies the total number of contracts over the 5-year period. Thirteen of the 51 respondents (25 percent) had less than one contract project per year.

Seven states and two FLHDs reported some unusual natural disaster (storms, earthquake, etc.), which may have skewed their average as reported in Columns 4A and 4B. California's Loma Prieta earthquake in October 1989 was one of these events. On the other hand, the California Department of Transportation (Caltrans) believed that the 5-year period chosen was not representative of the annual costs because of an unusual series of dry winters. Consequently, the value shown is considered to be on the low end of the expenditures for landslide corrections in California. Having lived in California since 1975, the author can confirm this observation from personal experience. Major-storm disaster declarations have

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Using the following basic definition of a landslide. "A landslide is the movement of a mass of rock, earth or debris down a slope".

Please answer the following questions and return the form no later than March 29, 1991, to the address below. Please write in your State name here.________________________

1. Over the past five years, what is the average <u>annual</u> cost of highway contracts let to correct landslides? ____________

2. How many contracts does this represent? ____________(5yrs)

3.a. Are landslides a significant cost on grading projects?
NO________ Yes________

b. In your opinion, if the costs of landslide mitigation on grading projects were added to 1 above, the annual costs would stay the same____ Double____ Triple____ Quadruple or more____

4.a. Over the past five years, has any disastrous event occurred to skew the above answers? No_____ Yes_____

b.If yes, please give the high $_____ and low $_____ annual costs and explain the event below.

5.a. In order to maintain a safe roadway surface, are landslide related activities by maintenance an identifiable cost in your state? No_____ Yes_____

b. If not, in your opinion do you feel it would be an appreciable cost? No_____ Yes_____

c. If yes to 5.a. please report the average annual maintenance cost for your department $___ and give an estimate of what percentage of the highway maintenance cost this represents ___%.

Additional comments: ________________________________
____

Optional: Your name________________________________
Would you like to receive a copy of the national tabulation?
No____ Yes____ (include business card)

FIGURE 1 Survey questionnaire: landslide mitigation costs on state highway systems.

occurred in 1978 (Los Angeles), 1980 (Los Angeles–San Diego), and 1982–1983 (San Francisco to Reno, Nevada), none of which are covered in the survey period of 1986 to 1990. In the 1978 and 1980 events, the total damage to property (not just highways) by landslides was reported to be $120 million (*7*). In the 1983 event, the closure of U.S. Highway 50 by landslides both east and west of South Lake Tahoe caused major economic loss to this resort area. The cost of repairs to the highway was $2.2 million at the California site and $1.4 million at the Nevada site. The estimated economic loss due to 2½ months of access disruption was $70 million (*8*, p.2). This is just one illustration that repair costs greatly underestimate the public's total cost due to landslides on highways or any transportation system.

As expected, the states with the large costs are those that include the principal mountain ranges. In addition, more is spent in those states with large populations or high densities along the East and West coasts. The total annual cost of contract landslide repairs on state highways is $68.5 million (see Table 2, Column 7), which averages out to be $472,000 per contract. On federal lands, the average repair cost is $881,900 per project. The high cost of this last group is most likely due to the remoteness of the sites in the federal land and parks, severe environmental constraints, and the need to keep access open to large numbers of visitors during construction.

It is also interesting to compare the costs by FHWA Region, as presented in the previous survey and summarized in Table 2. In Column 2, the 1976 costs are reported. If one inflates the 1976 costs by the national Construction Cost Index (*9*) for common excavation from 1976 to 1990 ($1.03/yd^3 to $2.38/yd^3; the factor is 2.31), the differences in expenditures by region between the two surveys from 1976 to 1990 can be evaluated by comparing Columns 3 and 4.

In the Northeast (FHWA Regions 1 and 3), the expenditures (in constant dollars) have remained essentially the same between the two periods. In the Southeast (Region 4) the annual costs have been reduced by 50 percent, but this region still has the highest average cost per state project in the nation ($824,000).

The Central portion of the United States (Regions 5, 6, and 7) shows the greatest reduction (75 percent) in landslide costs between 1976 and 1990, and also the lowest average repair costs ($215,400). Considering that the topography in the central United States is more level, this should be expected.

In the West, the trends are mixed, with an overall reduction of 35 percent. The Rocky Mountain region shows a dramatic reduction of 65 percent, and the Northwest (Region 10), an

TABLE 1 SUMMARY OF RESPONSES TO SURVEY QUESTIONNAIRE

QUESTION / STATE	1 AVE/YR $1000's	2	3A NO	3A YES	3B SAME	3B 2X	3B 3X	3B 4X	4A NO	4A YES	4B HIGH	4B LOW	5A NO	5A YES	5B NO	5B YES		5C $1000's	5C %	RESPONDENTS TO QUESTIONNAIRE AND COMMENTS
MAINE	300	10																		
NEW HAMPSHIR	500	10		X		X			X					X				500	1.00	NH: F. E. PRIOR
VERMONT	200	5	X		X				X				X		X					VT: C. C. BENDA
MASSACHUSETT	1000	25	X		X				X					X				2000	2.00	MA: N. M. HOURANI
RHODE ISLAND	0		X		X				X				X		X					RI: J. A. DIFILIPPO
CONNECTICUT	100	3	X		X				X				X		X					CT: S. M. ZYSKOWSKI
NEW YORK	6000	7	X		X					X	6000	1000		X				426	0.20	NY: E. A. FERNAN (A)
DELAWARE	0	0	X		X				X				X		X					
PENNSYLVANIA	10000	105		X		X			X				X			X				PA: C. T. JANIK (B)
NEW JERSEY	0		X			X			X				X		X					
WEST VIRGINIA	1288	33		X		X			X					X				2241	1.50	WV: G. L. ROBSON
MARYLAND	200	4		X				X		X	1000	25		X				25	0.02	MD: A. D. MARTIN (C)
VIRGINIA	NR																			
KENTUCKY	2009	10		X		X	X		X					X				2770	3.00	KY: E. H. ADAMS
TENNESSEE	1000	15	X			X			X					X			(D)	762	2.00	TN: W. D. TROLINGER (D)
NORTH CAROLIN	3000	5	X		X					X	6000	500		X				1500	5.00	NC: P. A. KEANE
SOUTH CAROLIN	320	3	X			X			X				X		X					SC: F. MCRANEY
GEORGIA	100	10	X			X				X	1200	200		X				600	0.50	GA: B. R. MCWHORTER
ALABAMA	1758	7	X		X				X				X		X					AL: S. ARMSTRONG
MISSISSIPPI	5000	30	X		X				X				X		X			1000		MS: J. D. WEBB
FLORIDA	0		X						X				X							FL: J. CALIENDO
MINNESOTA	500	3	X		X				X				X		X					MN: R. A. ADOLFSON
WISCONSIN	400	4	X		X				X				X		X					WI: C. A. LAUGHTER
MICHIGAN	50	2	X				X		X				X		X					MI: D. D. DOLPH
ILLINOIS	1436	26	X		X				X					X				150	0.05	IL: J. S. DHAMZAIT
INDIANA	300	12	X		X				X					X				200	6.00	IN: W. D. DAVIS (E)
OHIO	NR																			
NEBRASKA	100	6	X		X				X					X				100	0.20	NE: K. CHENEY
IOWA	87	7	X					X					X		X					
KANSAS	600	25	X		X				X				X			X				KS: J. J. BRENNAN
MISSOURI	231	15	X		X				X					X				458	0.22	
OKLAHOMA	489	5	X		X				X				X			X		106		OK: J. B. NEVELS JR.
ARKANSAS	600	20	X			X			X				X		X					AR: J. E. CLEMENTS
NEW MEXICO	1250	5				X	X		X					X				400	0.60	NM: E. RECTOR
TEXAS	1164	22	X		X				X				X			X	(F)	2375		TX: H. ALBERS (F)
LOUISIANA	419	25		X			X		X				X			X				LA: J. B. ESNARD JR.
MONTANA	1000	10		X		X			X				X		X					MT: T. L. YARGER
NORTH DAKOTA	11	1	X						X				X		X					ND: R. HORNER
SOUTH DAKOTA	540	6		X					X				X			X				SD: W. C. SULZLE
WYOMING	1125	17	X		X					X	3500	45		X				290	1.00	WY: G. W. RIEDL
COLORADO	300	3	X				X		X				X			X		3500	3.30	CO: R. K. BARRETT
UTAH	1777	7	X			X			X(G)					X			(H)	414	1.00	UT: E. G. KEANE (G)(H)
ALASKA	800	7	X		X				X					X		X		300	0.60	AK: M. WEAVER
WASHINGTON	5846	24	X		X				X				X		X					WA: S. M. LOWELL
OREGON	3150	35	X		X	X								X		X		378	1.90	OR: G. MACHAN
IDAHO	500	8	X		X	X			X	X	4171	50	X			X				ID: T. BUU
CALIFORNIA	7333	115	X	X(I)	X					X	11933	4000	X	X				15292	4.20	CA: R. H. PRYSOCK (I)
NEVADA	432	7	X						X				X			X				NV: J. M. SALAZAR
ARIZONA	500	6	X		X				X				X	X				150	1.00	AZ: S. B. KAY
HAWAII	2000	5		X		X			X					X		X		1500	12.00	HI: D. D. SANTO
WFLHD (J)	1000	5		X	X					X	1900			X		X				WFLHD: A. PETERS (J)
CFLHD (K)	995	6		X	X				X											CFLHD: S. HOLDER (K)
EFLHD (L)	827	5	X			X				X	1690			X						EFLHD: J. J. AMENTA (L)
TOTALS	68537	726	38	12	27	16	5	2	40	9			28	23	16	13		37437		

(A) Annual costs broken down to $3 million for rock and $3 million for soil
(B) Large number of sites need permanent fixing at $300K to $2000K each. Maintenance cleans 50 to 150 sites/year but no identifiable costs.
(C) Single storm event averaged over five years
(D) Single storm event of $762K
(E) Two-year data
(F) Nine of 24 districts responded with partial data typically covering one- to three-year data.
(G) Major storms occurred in 1982–83 causing widespread damage in the West. In Utah, the Thistle slide alone cost the DOT $31,5000,000. This repair is not included in column 1.
(H) Excellent district-by-district maintenance costs.
(I) Some coastal districts reported major costs for remedial measures during construction.
(J) Western Federal Lands Highway Division
(K) Central Federal Lands Highway Division
(L) Eastern Federal Lands Highway Division

appreciable 35 percent reduction. Only Region 9 shows an increase, probably because the previous survey was limited to Federal-aid participation. Consequently, it did not include the large number of projects or contracts performed by these four states that were considered maintenance by FHWA and were not eligible for federal funds.

Further analysis of the differences by region between the two surveys is beyond the scope of this paper. Overall, the direct cost of unanticipated landslide repairs appears to have reduced by 40 percent, which is substantial.

Liability Costs

In the United States, another significant and often delayed hidden cost is that of litigation. Sometimes enormous settle-

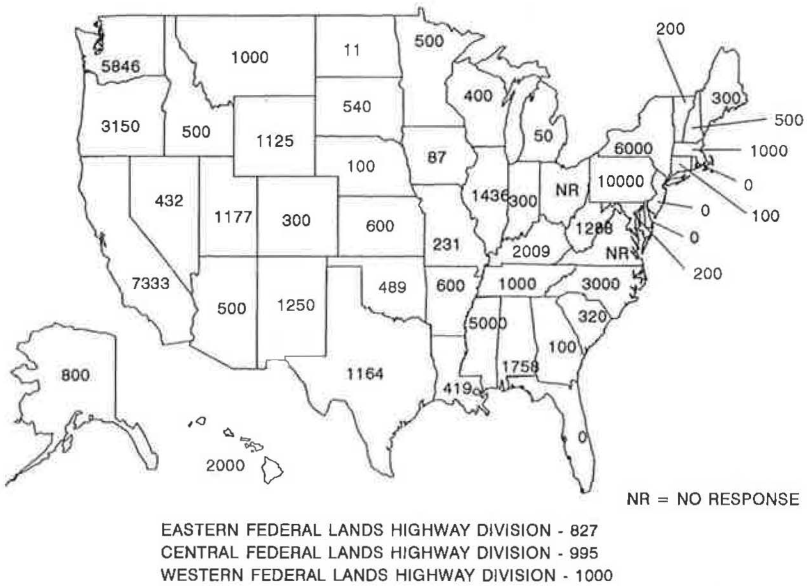

FIGURE 2 Average annual costs (in thousands of dollars) of contracted landslide repairs on state highway systems (1986–1990).

TABLE 2 COST COMPARISON OF CONTRACTED LANDSLIDE REPAIRS BY FHWA REGION

FHWA Region (States)	1976 Annual Costs Reported	1976 Costs Inflate to 1990 By Factor 2.31	1990 Annual Costs Reported	5-Year Cost 1986-1990	Number of Projects 1986-1990	Average Cost Per Project U.S. $
	Costs in columns 2, 3, 4, 5 are in million $					
1	2	3	4	5	6	7
1.ME,NH,VT, MA,RI, CT, NY	3.0	6.930	8.100	40.500	60	675,000
3.DE,PA,NJ, WV,MD,VA	6.0	13.860	11.488	57.440	142	404,500
4.KY,TN,NC,SC GA,AL,MS,FL	12.0	27.720	13.187	65.935	80	824,200
Subtotal(1,3,4)	21.0	48.510	32.775	163.875	282	581,100
5.MN,WI,MI IL,IN,OH	4.0	9.240	2.686	13.430	47	285,700
6.OK,AR,NM,TX,LA	7.0	16.170	3.922	19.610	77	254,700
7.NE,IA,KS,MD	1.0	2.310	1.018	5.090	53	96,000
Subtotal (5,6,7)	12.0	27.720	7.626	38.130	177	215,400
8.MT,ND,SD,WY, CO,UT	6.0	13.860	4.753	23.765	44	540,100
9.CA,NV,AZ,HI	3.5	8.085	10.265	51.325	133	385,900
10.AK,WA,OR,ID	7.0	16.170	10.296	51.480	74	695,700
Subtotal(8,9,10)	16.5	38.115	25.314	126.570	251	504,300
FLHD	NA	NA	2.822	14.110	16	881,900
Totals	49.5	114.345	68.537	342.685	726	472,000

ment costs are associated with these suits. For example, plaintiffs in Malibu (near Los Angeles) won settlements of $45 million for damages as the result of slides and rockfall on slopes that otherwise had minimal problems for more than 30 years. Caltrans is by no means the only highway agency that has experienced a severe blow to its budget from litigation. The New York Thruway Authority, a totally separate agency from the New York Department of Transportation (NYDOT), will spend $35 to $41 million in the next few years to stabilize some 35 rock cuts. This concentrated flurry of activity is the consequence of a lawsuit filed following a fatal accident involving fallen rock. This also is not reflected in the value of $6 million per year reported by the NYDOT respondent.

Preventive Mitigation Costs

The survey concentrated on obtaining costs for the correction of active or unanticipated landslides that had caused damage to the state highway network. It does not begin to reflect the mitigation costs expended on new projects to maintain an acceptable safety factor against failure of problem sites identified during the design phase. These costs can range from the multi-million-dollar stabilization measures needed to cross an existing landslide area to the "extra" thousands of dollars spent on the use of retaining walls to keep an existing cut slope or embankment within the right-of-way available to the designers.

If each of these costs could be rationally identified, the real cost to society for mitigation and correction of slope stability problems could be more accurately presented.

Maintenance Costs

About half the respondents reported that they could not identify landslide repair as a specific activity of the state's maintenance program. On the survey form, the author chose the definition of the term "landslide" approved by the International Association of Engineering Geology (IAEG) Commission on Landslides and Other Mass Movements on Slopes: "A landslide is the movement of a mass of rock, earth or debris down a slope" (*10*).

The term "mass" may have been misinterpreted by many as implying a large quantity of material. Technically, it means any volume of material, such as a single rock, which requires removal from the roadway prism by maintenance personnel. In most agencies, rock or slide debris removal is not an identifiable activity; thus, it is not indicated as a separate cost item.

Another very common maintenance activity that is difficult to identify by purpose is pavement patching. This work is performed to correct many different roadway deficiencies, such as potholes or settlement due to poor compaction, but also to restore grade over slow-moving slides. There are thousands of sites like these on the highway system that rarely get proper geotechnical evaluation and are not included in cost estimates.

These previous observations are not by themselves surprising. What is surprising is the reported total maintenance costs of $37,437,000 spent annually for landslide correction by the 23 states providing data. Seven of these (Massachusetts, West Virginia, Kentucky, Missouri, Texas, Colorado, and California) spend as much as 10 times more than the contract amounts (Table 1, Column 5C). California distinguishes itself by reporting the highest annual costs for landslide maintenance of over $15 million, even during 5 years of low rainfall. However, this expenditure represents only 4.2 percent of California's total maintenance budget. Only two states, Hawaii and North Carolina, reported higher overall percentages of their total maintenance costs for landslide maintenance. However, in other states, several counties or districts may consume up to 30 percent of their individual budgets for landslide cleanup, and proper repairs are rarely made.

For most states with records, landslide maintenance represents 1 to 2 percent of the overall cost of operating existing highways. Nationally, 1 percent of state maintenance expenditures totals $76,290,000 per year (*6*). If one looks at the total public highway system, 1 percent of the maintenance costs adds up to $196,790,000. With such large sums being spent for maintenance on the national highway system, it is no wonder that more than half of the respondents could not identify an item constituting such a small percentage. However, of this half, many expressed the opinion that the costs would be quite significant. A common complaint was that maintenance personnel waited too long before requesting help from the geotechnical staff. As a consequence, small problems developed into large ones that were costly to fix.

Three states were able to provide very detailed landslide maintenance costs: Utah, California, and Texas. Other states have started programs to inventory their landslide problem areas in order to set priorities for the expenditure of capital funds for corrections. For example, in 1987 the Washington Department of Transportation (WSDOT) conducted a statewide inventory of all identifiable unstable slopes. Those in need of repair totaled 180, with an estimated repair cost of $190 million. On the basis of research performed since then, WSDOT geotechnical engineers can now provide management with decision-making tools so that they can program sites for correction. Without such an effort on the part of the geotechnical staff, it is clear that the past expenditures of $5.8 million per year would not be representative nor would they begin to solve that state's landslide problem.

CONCLUSIONS

This survey has identified that the correction of damage to the state highway system by landslides costs at least $106 million per year. There was much evidence in the responses from the highway agencies that this is only a fraction of the total cost to the public that relies on the highway system for their mobility and livelihood.

When compared with the 1976 survey, this survey gave strong evidence that less money was being spent annually to correct unanticipated failures during this period (1986 to 1990). This can be attributed to better staffing and technical expertise in geotechnical engineering by a number of state departments of transportation.

Those that have received proper support by management show the most cost-effective results. Certainly another reason is the fact that the major construction phase on new alignment of the Interstate highway system is coming to an end. On the other hand, it is quite clear that most states do not have any inventories of their landslide problems, and consequently cannot report adequately on their landslide repair-cost needs. One state that did respond reported its needs as 30 times its current annual expenditure. If this ratio held true nationally, the states' needs would be over $2 billion.

In the meantime, maintenance personnel are still faced with large expenditures to clear or patch the roadways damaged by landslide activity. From partial records, some $37 million annually was identified for landslide maintenance. This also must represent only a fraction of the real costs. This survey confirmed that landslide costs are much larger than most highway engineers believe and that better inventories of this problem are needed.

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