Controls at a Low Water Stream Crossing

Various controls have been used to delineate the edges of the traveled way at an LWSC. Curbs are generally unacceptable because the flow of water tends to deposit mud and debris on the roadway. Attempts have been made at a few locations to create a series of small, raised curb blocks with tapered upstream slopes to provide for a smooth laminar flow. The use of any projections above the normal roadway surface will have an adverse effect on the self-cleaning aspect of the smooth cross-section. However, observations of existing applications, or further research in this area, are needed.

REFERENCES

1. *Soils Design Procedure SDP-2: Bank and Channel Protective Lining Design Procedures.* Bureau of Soil Mechanics, State of New York Department of Transportation, Albany, 1971.
2. M. P. Keown, N. R. Oswalt, and E. B. Perry. *Literature Survey and Preliminary Evaluation of Streambank Protection.* WES Report RE-H-77-9. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Miss., 1977.
3. V. T. Chow. *Open-Channel Hydraulics.* McGraw-Hill Book Company, New York, 1959.
4. R. L. Carstens and R. Y. Woo. Liability and Traffic Control for Low Water Stream Crossings. *Engineering Research Institute Project 1470 Final Report.* Iowa State University, Ames, 1981.

Guidelines for the Design of Low-Cost Water Crossings

LOUIS BERGER, JACOB GREENSTEIN, AND JULIO ARRIETA

In Ecuador, as in many Third World countries, low-volume rural roads can only be economically justified when very low-cost bridges and simple water crossings (fords) are used. Traffic analyses indicate that in most cases the trucks that travel these roads carry loads that weigh less than 6 to 10 metric tons. Therefore, most of the drainage structures are designed to carry only 10 tons on two-axle light vehicles. Roads are designed according to AASHTO HS-15 standard loading in those locations where heavy traffic is generated from timber production or banana plantations. The standard AASHTO HS-20 live load cannot be economically justified for these low-volume roads. The traffic volume in rural regions is very low, which enables such economical structures as graveled fords to be used, and, when economically feasible, one-lane bridges with either complete or split decks. The relationships between the type of material, the span or length of the superstructure, and the cost are analyzed. It is primarily concluded that simple timber bridges made of stringers and transverse laminated decks are the most economical solutions for simple spans up to 17, 14, and 10 m for 6-, 10-, and 24.5-ton truckloads, respectively. Simple-span, split-deck, reinforced-concrete superstructures are feasible for spans of up to 30 m. Spans can be as long as 45 m if prestressed girders are used. Suspension bridges with timber decks and timber-stiffening trusses were built to carry 6-ton trucks or cattle wagons and were more cost-effective than timber or concrete structures. It was concluded that with the judicious reduction of the design standards of live loads, cross-sections, geometry, material specifications, and hydrologic and hydraulic considerations, construction costs could be reduced by 50 percent or more. These savings make it possible to justify the construction of many low-volume rural roads that would otherwise be impossible to finance.

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Low-volume roads are needed in such developing countries as Ecuador and Colombia to provide access in agricultural and rural regions (*1, 2*). A socioeconomic analysis is performed to determine which type of road is the most economical to build. The use of this methodology enables the least-cost road to be determined for any given traffic projection, degree of agricultural productivity, and extent and type of social and population activities.

Several types of low-cost rural roads exist in Ecuador: (a) earth or dirt roads that are 2.5 to 4.0 m wide and provide access only during the dry season, (b) 4.0- to 6.0-m-wide compacted subgrade or gravel roads, (c) 4.0- to 5.0-m-wide stone roads constructed mainly in the Andes region, and (d) 6.0- to 7.2-m-wide base course roads with or without blacktop. Construction of most of these low-volume roads can be economically justified only if the construction cost is minimized to achieve a feasible rate of return on the investment. The minimum initial rate of return required to justify investment in the construction of low-volume roads in Ecuador in 1984 to 1985 was 12 percent. This objective can be achieved only if low-cost water crossings are used to provide access.

The economic horizon or lifetime of a low-cost road in Ecuador is 17 years. It was concluded in a study financed by the World Bank that all agricultural and other economic benefits could be achieved during this 17-year period, and the investment therefore would be justified (*2*). The minimization of costs and maximization of benefits during the economic horizon are both needed to optimize and justify road and bridge construction. Cost savings can be obtained by setting appropriate standards for certain design elements, such as design load, cross-sections, low-cost materials, and hydrologic and hydraulic design criteria, even though these criteria may appear to be substandard to the developed world.

Typical low-cost bridges and water crossings in Ecuador are shown in Figures 1 to 5. A one-lane timber bridge in Puerto Viejo, Ecuador, that was designed to carry only one vehicle at a time with a total weight of less than 6 tons is shown in Figures 1a and 1b. A one-lane timber deck in Puerto Bartelo, Ecuador, that was designed to support a truck carrying less than 10 tons is shown in Figures 2a and 2b. A typical one-lane concrete and steel split deck that can carry one truckload of less than 10 tons is shown in Figures 3a and 3b. A one-lane concrete bridge that was designed to carry HS-15-44 trucks with a total weight of 24.5 tons is shown in Figures 4a and 4b. A ford-type water crossing is shown in Figures 5a and 5b. This type of ford is very common in the Ecuadoran Andes.

Basic design guidelines, typical cross-sections, and cost comparisons of low-cost bridges and water crossings in Ecuador are presented.

LIVE LOAD DESIGN

It is well-known that the transport of goods in the Third World is mainly performed by the private sector, which saves money by overloading its trucks. Recent projects in Ecuador and Colombia financed by the World Bank indicate that little is currently being done on the main roads to control truck overloading. This conclusion also appears to apply to other countries. As a result of this evidence, the structural division in the Ecuadoran road authority designed all bridges for both main and rural roads according to the AASHTO HS-20 standard truck loading. The lower AASHTO standard HS-15


(a)

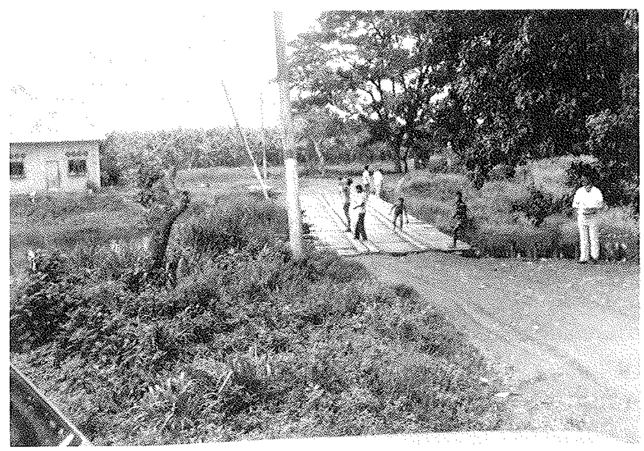

(b)

FIGURE 1 Two views of a timber bridge.


(a)

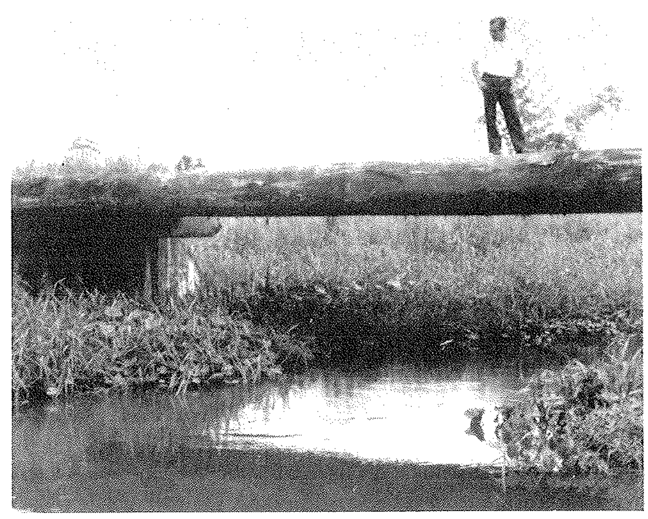
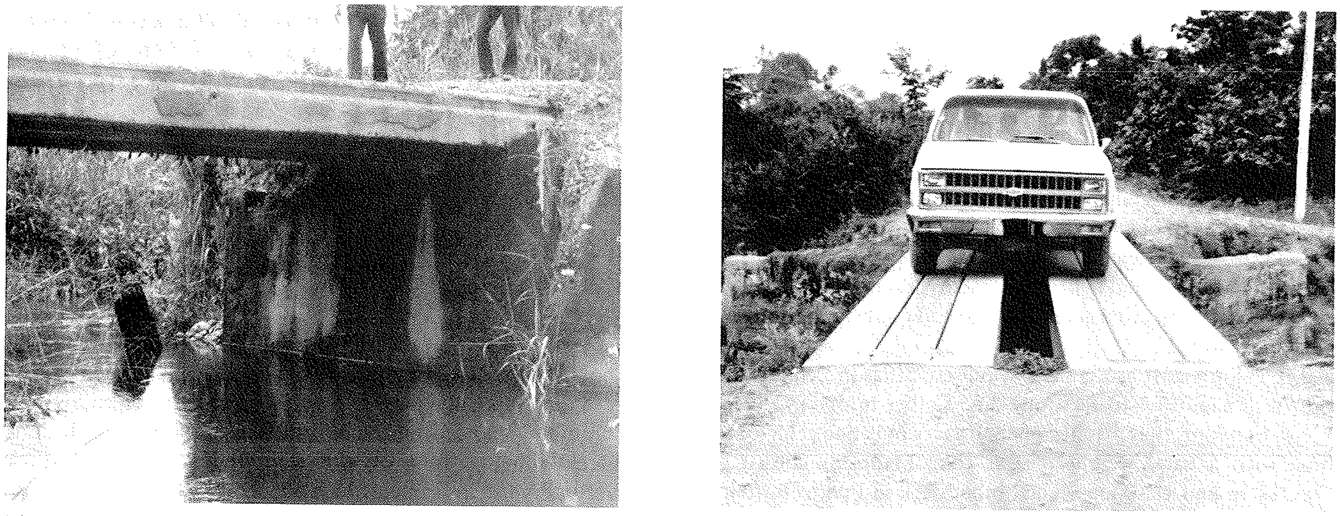
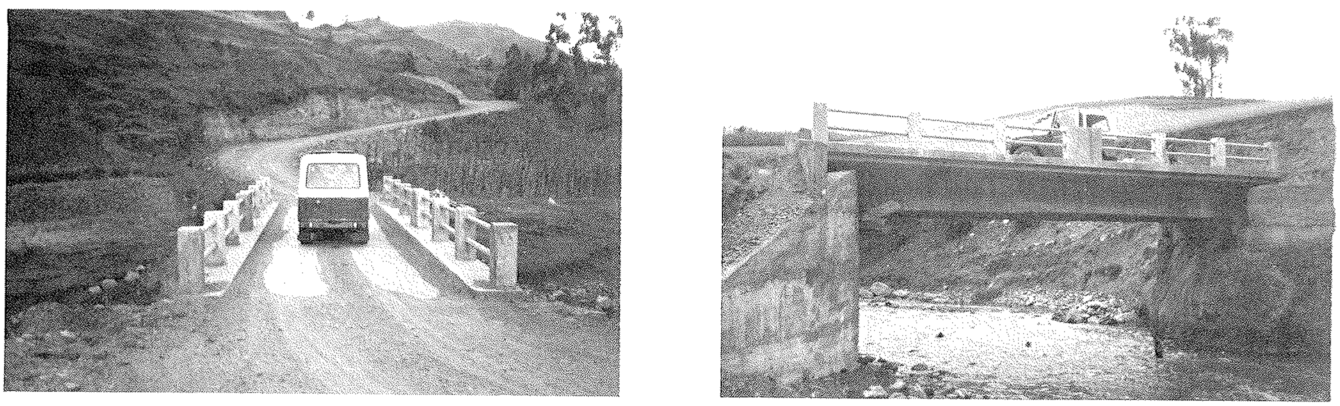

(b)

FIGURE 2 Two views of a timber deck.



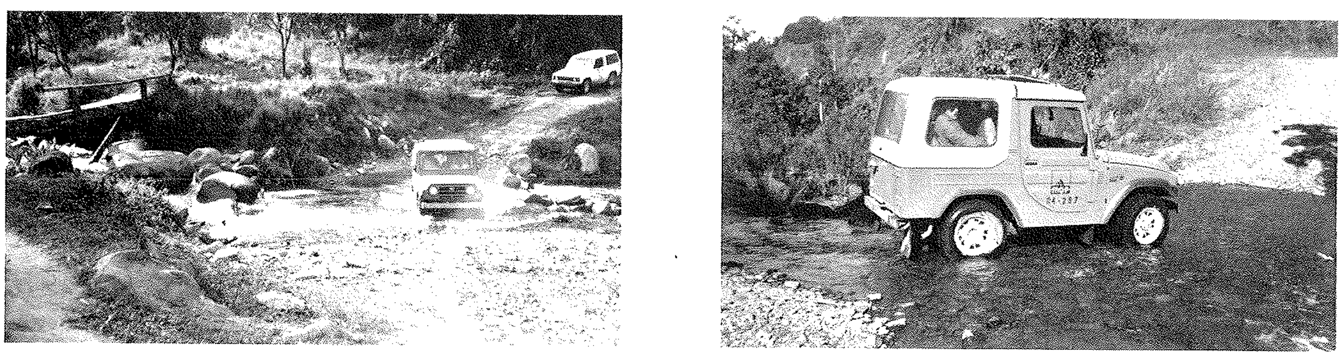
(a) (b)

FIGURE 3 Two views of a one-lane, split-beam deck.



(a) (b)

FIGURE 4 Two views of a one-lane concrete bridge design for HS 15-44.



(a) (b)

FIGURE 5 Two views of a low-cost ford in the Ecuadoran mountainous zone.

truck was only occasionally used in the design of rural bridges. Recent economic and transport studies in Ecuador indicate that the actual vehicle loading on rural roads is significantly lower (*1-3*). The largest vehicle on over 90 percent of the roads is a two-axle truck with a total weight of less than 10 metric tons. About 75 percent of the vehicles are pick-up trucks and light buses and trucks, with a total weight of 2 to 6 tons. An economic and traffic projection analysis indicated that the volume of traffic might increase slightly in most of the existing Ecuadoran rural roads, but no changes in vehicle type or total weight are expected (*1, 2*). In other words, the projected demand and economic growth, and the low standard of the road and pavement, make the use of oversized or overloaded vehicles infeasible (*1, 4*). Only in a few rural locations—regions with heavy traffic from timber-producing regions or banana plantations—can a AASHTO standard HS-15 live load be economically justified. These relatively few roads usually have higher design standards; a 6.0- to 7.2-m-wide base course pavement with or without blacktop is usually used. Based on these economic and traffic forecast analyses, the Ecuadoran road authorities decided that it was practical and economical to adopt lower design standards for live loads on most of the low-cost rural bridges. The following three load categories were adopted (see Figure 6):

- An M6 truck with 1,200 kg and 4,800 kg on the front and rear axles, respectively;
- An M10 truck with 2,000 kg and 8,000 kg on the front and rear axles, respectively; and
- An HS-15 load with 2,720 kg on the front axle and 10,880 kg on each of the two rear axles, for a total of 24,480 kg.

The AASHTO standard HS-20 live load was not found to be economically justified for these low-cost roads.

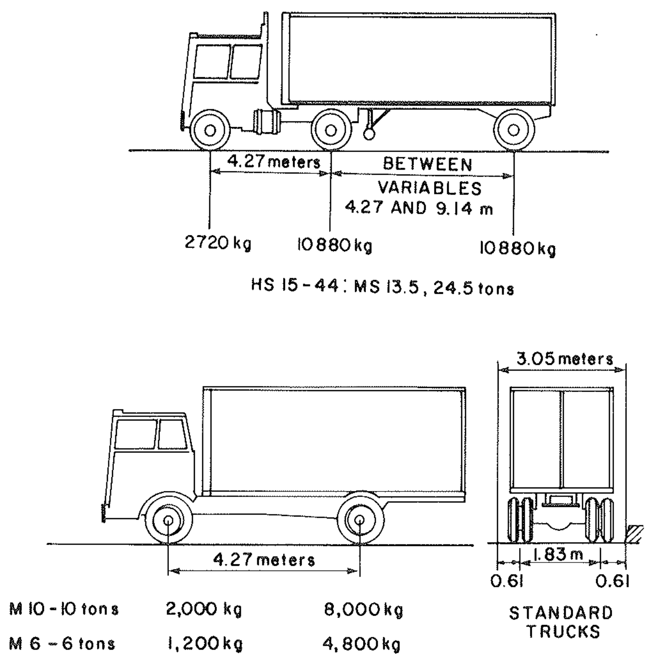


FIGURE 6 Two designs for live loads on rural bridges.

HYDRAULICS AND HYDROLOGY

The deforestation that occurred in Ecuador the last few years has resulted in severe flooding in rural regions. The deforestation also caused an increase in the flooding discharge and a reduction in its duration. The deforestation and changes in flooding characteristics occurred more often in the rural or remote regions and less often in the vicinity and area of influence of major highways. Previous hydraulic records for rural bridges therefore should be analyzed with caution to prevent rural bridges from failing during floods, as shown in Figures 7a and 7b. A typical scour failure in a rural road bridge in the Ecuadoran province of El Oro is shown in Figure 7a. The scouring caused 1 ft of settlement in the center abutment. The bridge is still used for light and partially loaded trucks.

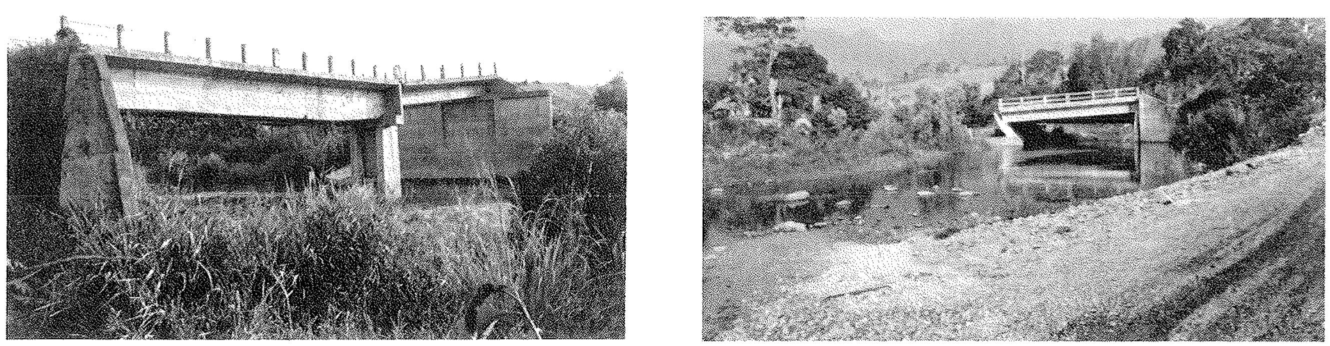
A typical total bridge failure that was caused by flooding in 1982 is shown in Figure 7b. Although the hydraulic analysis should be precisely executed to eliminate any unexpected failures, especially in cases in which changes have recently occurred in the flooding pattern, the hydraulic design criteria should permit bridge construction costs to be minimized. The criteria for main roads specify or require that the clearance between the bridge's bottom deck and the maximum flood level should be 1 ft (30 cm) for the occurrence of a storm every 100 years. In rural road design, the storm period can be reduced to 25 years. This period is approximately equal to 150 percent of a road's economic lifetime. Experience also indicates that the water clearance should remain at 1 ft unless the water velocity is slow and accumulation of debris is not expected. A slow stream is defined as one in which the slope is less than 0.5 percent and the maximum velocity is below 10 ft/sec.

LOW-COST BRIDGES

Concrete Bridges

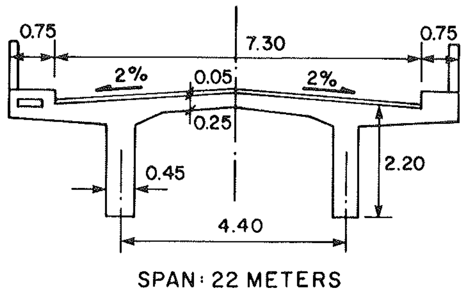
Before 1984, the Ecuadoran rural bridges were designed according to AASHTO standards (*5*). A cross-section of a typical two-lane bridge is shown in Figure 8. Such bridges were designed in 1980 to carry an AASHTO standard HS-20 truck. Because two-lane bridges were found to be economically infeasible for rural roads, a new standard was established (*1, 2*).

A one-lane bridge (Figures 9a and 9b) was established as the highest standard that could be economically justified for rural

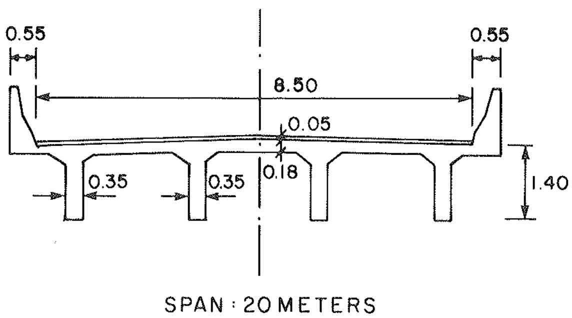


(a) (b)

FIGURE 7 Two views showing typical bridge flood failure in the province of El Oro.

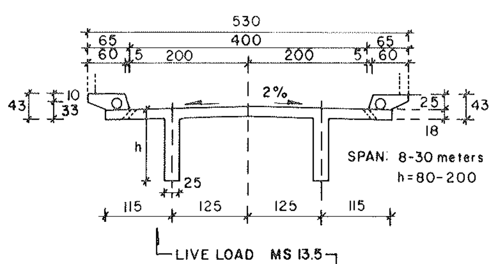


(a) ESTERO LUNA GRANDE, ECUADOR

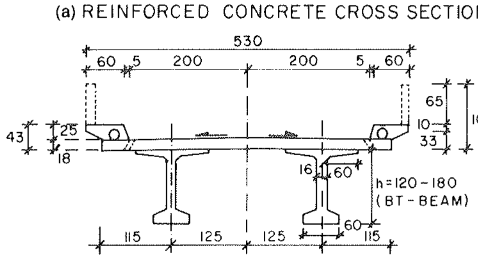


(b) ESTERO LUNA CHICO, ECUADOR

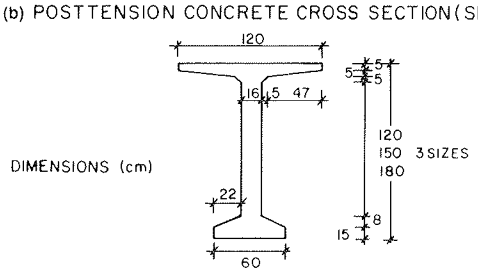
FIGURE 8 Typical two-lane rural bridge design for AASHTO HS-20 truck loading in Ecuador.



(a) REINFORCED CONCRETE CROSS SECTION



(b) POSTTENSION CONCRETE CROSS SECTION(SPAN 24 TO 42 M)



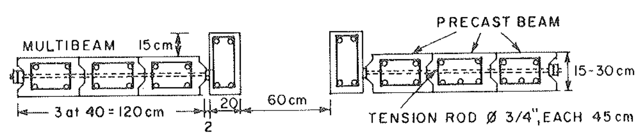
(c) BULB-T BEAM

FIGURE 9 (a) One-lane reinforced concrete bridge cross-section; (b) one-lane post-tensioned concrete cross-section.

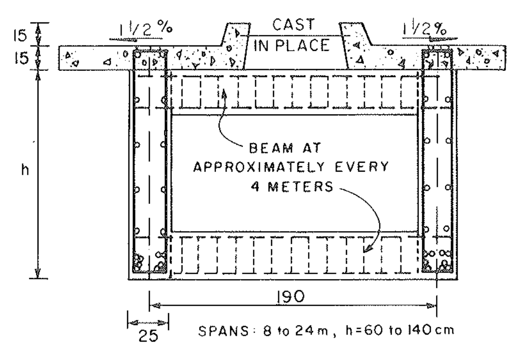
roads. The bridge cross-sections shown in Figures 9a and 9b are designed to carry an AASHTO standard HS-15 truck. A reinforced concrete cross-section that is usually feasible for a span of 8 to 30 m is shown in Figure 9a. A post-tensioned concrete cross-section that is usually feasible for spans between 25 and 45 m in length is shown in Figure 9b. The sidewalk and guardrail shown in Figure 9b are provided when pedestrians, cattle, and vehicles are to use the bridge. Cattle can use the bridge only if it crosses deep water.

An economical one-lane, split-deck bridge is shown in Figures 10a, 10b, and 10c. The split cross-sections shown in these figures are used for 6- and 10-t trucks (M6 and M10). A simple, multibeam, precast concrete bridge is used for short spans of usually 8 m or less. The construction procedure is very simple. The slabs are precast on the river bank and are easy to place and tie together to form the split deck. A typical cast-in-place split-deck bridge that is primarily used for bridge spans of 8 to 24 m is shown in Figure 10b. Cast-in-place, reinforced concrete bridges are popular in developing countries, such as Ecuador, Peru, and Colombia. This technique is also well-known to local industry. In addition, the only materials that have to be transported to the site are the reinforcing steel and cement.

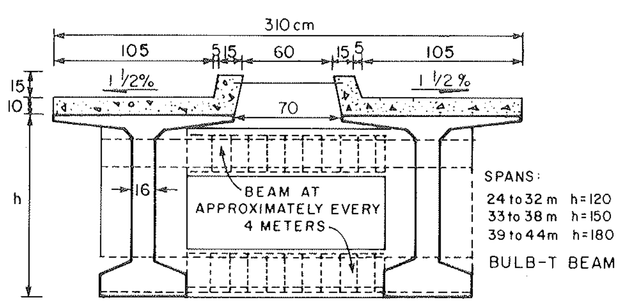
The simple, split-lane reinforced bridge shown in Figure 10b is light and safe to use by vehicles and pedestrians. It is worthwhile to mention that the geometry of the split lane with the inside curb shown in Figures 10a and 10b contributes to its traveling safety. The split lane contributes naturally to speed



(a) MULTIBEAM SPLIT DECK



(b) PRECAST DECK



(c) POSTTENSION CONCRETE BEAM

FIGURE 10 Typical split deck for low-cost bridges.

reduction and the inside curb is effective in preventing vehicles from sliding off the bridge. A split deck with prestressed girders of the sort shown in Figure 10c is more feasible in Ecuador when the single span exceeds 24 m.

In developing countries, such as Ecuador, Colombia, and Peru, the required pretensioning equipment is usually not available at a reasonable distance from the site; therefore, most of the prestressed bridge elements are post-tensioned. Standard post-tensioned girders and cast-in-place slabs that are practical for low-cost bridges with spans ranging between 25 and 45 m are shown in Figure 10c. Long, low-cost bridges are rarely constructed with a single span of over 45 m.

Each of these cases has been studied in detail in regard to the live load and bridge element type. The live load of bridges on roads classified as low-volume and low-cost in Ecuador consists of cattle or a maximum truckload of 6 tons.

Timber Bridges

In the past few years timber has played an important economic role in the construction of low-cost bridges in countries that comprise the Pacto Andino, which include Colombia, Venezuela, Ecuador, Peru, and Bolivia. These countries are rich in natural resources, especially in their huge tropical and subtropical zones. New technology in regard to timber structural elements is provided through the Agreement of Cartagena-Colombia. This agreement provides assistance and technology for the classification of timber, improved mechanical properties, pest control, and processing and treatment of timber (*6*). Further information on the design and use of timber bridges is available elsewhere (*7-9*).

It was determined that the currently unlimited source of natural raw materials, and the availability of technical assistance in production, make timber a feasible and practical alternative for bridge construction (*6*). Two other factors contribute to the feasibility of using timber for rural bridge construction. First, timber elements, especially in decks, are light; they weigh approximately one-third to one-fourth of the weight of an equivalent concrete deck. The use of timber therefore reduces foundation costs. Second, the economic life of a rural road is only 15 to 20 yrs; therefore, the investment in lumber treatment can and should be limited to this period only.

A simple Ecuadoran timber bridge with a laminated deck is shown in Figures 11a and 11b (*3*). The cross-sections are made of timber stringers that span between abutments or piers and transverse laminates that are nailed to one another and to the stringers. The transverse laminates are sometimes spanned over trussed or solid-web girders. The timber deck cross-section shown in Figure 11b was designed to a maximum span length of approximately 17, 14, and 10.5 m for truckloads of 6, 10, and 24.5 tons, respectively. This structure is economical, quick and easy to construct, and easy to maintain.

The design guidelines for the dimensions and optimum location or separation of the stringers to carry these traffic loads are shown in Figure 11b (*3*). For example, for a span of 10-m, relatively heavy stringers 25 cm wide and 50 cm high should each be spaced at 1.35, 0.85, and 0.60 m to carry live loads of 6, 10, and 24.5 tons, respectively. The maximum and most economical timber deck span can be increased by approximately 40 percent by using longitudinal or transverse cable post-tensioning. The implementation of this technique is still very limited in the developing countries of South America.

Another type of low-cost timber bridge was developed and implemented by the United Nations Organization for Industrial Development (UNOID). This prefabricated timber bridge consists of triangular moduli 3 m long that are joined together at the site. These short elements are easy to transport. Like the other timber bridges that were previously described, the UNOID bridge can be assembled easily by unskilled labor.

A typical cross-section of a UNOID bridge is shown in Figure 12. This one-lane timber bridge is now promoted in

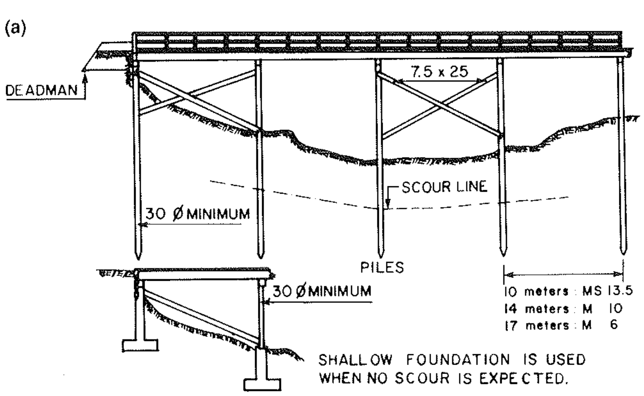


FIGURE 11 Typical timber bridge with laminated deck.

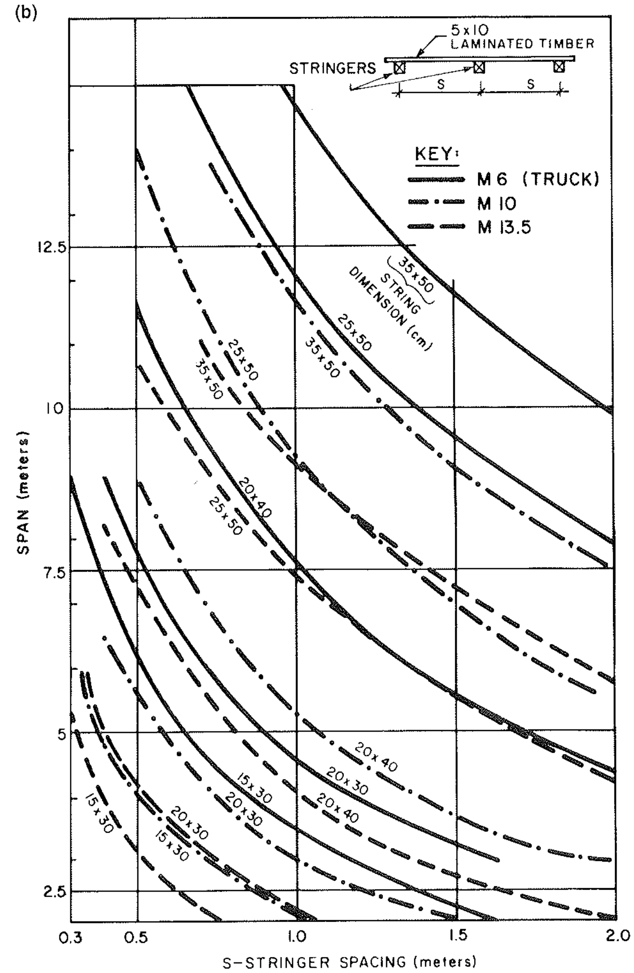


FIGURE 11 continued

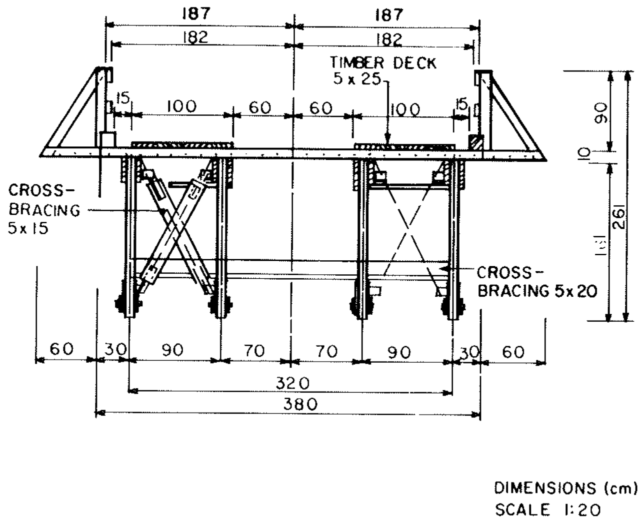


FIGURE 12 ONOID timber bridge.

Africa, Central America, and Ecuador by the United Nations and is designed to carry 6-, 10-, and 24.5-t trucks in a single span of 24, 21, and 15 m, respectively. As was mentioned previously, a long, single-span low-cost bridge is only occasionally needed for both vehicles and cattle. This special need primarily exists in the eastern tropical Ecuadoran Amazonas region. A typical bridge is shown in Figure 13. This bridge is designed only for light vehicles of 6 t or less, or for passing cattle. The spans of this single bridge vary between 45 and 120 m; the only nontimber elements are the reinforced concrete towers, the anchor blocks, and the cable.

Other Low-Cost Water Crossings

In many cases in which international or government funds are limited and timber for split-deck bridges is unavailable, other

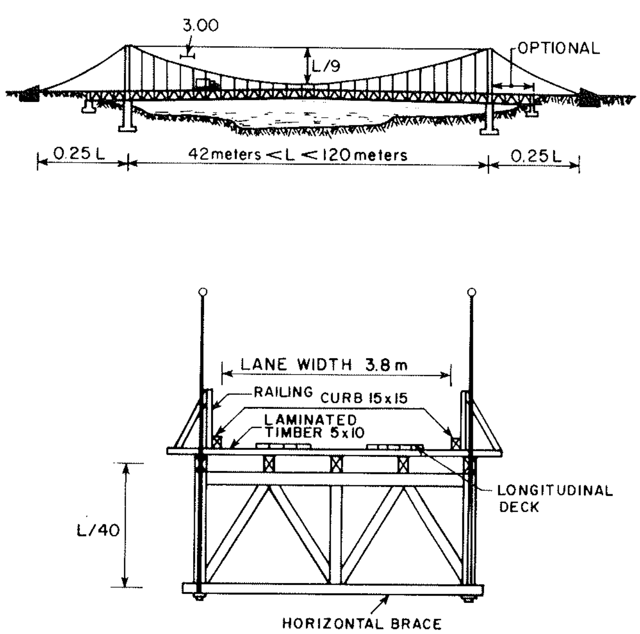


FIGURE 13 Single-span bridge with timber deck and timber-stiffening trusses.

low-cost water crossings can be built. In most of these cases, good judgment and experience with locally available materials can be used instead of standard specifications and structural analysis. The most commonly used and economical types of water crossings in Ecuadoran rural regions are described in the following paragraphs. All three types provide reasonable access for 3 to 5 yrs with no major repairs.

One type of low water crossing consists of beams of solid webs that are nailed to two flanges made of two layers of boards that support a split in the timber deck. This structure is used in spans of up to 25 m and mainly carries vehicle loads of less than 6 tons. This structure can deteriorate rapidly if moisture accumulates between the boards.

A no-stringers deck is designed for span lengths of up to 12 m. The bridge is made of timber laminates that run parallel to its longitudinal axis. These laminates are the only element in the superstructure.

Graveled fords are commonly used in the mountainous regions of Ecuador (Figure 5). Fords are used as low-cost water crossings on almost every unpaved rural road in this region. A typical cross-section of a ford is shown in Figure 14 for both steep and flat water crossings. The construction of this type of crossing is usually labor-intensive. The surface of graveled forms usually performs adequately for 3 to 5 yrs in the Ecuadoran Andes. Maintenance is rather simple; it is also performed by manual labor with a relatively minor cost. Experience in Ecuador clearly indicates that the construction and maintenance costs of a ford are always less than a fraction of those for a single-lane, low-cost bridge. They cost approximately 50 to 100 U.S. dollars/linear meter when local materials are available.

COST COMPARISON

The construction costs of rural concrete bridges that are designed to carry AASHTO standard HS-20 trucks are given in Table 1, in which the costs of the bridge deck and the bridge as a whole are broken down. As shown in Table 1, the total construction cost of a two-lane, 8.5-m-wide concrete bridge varies between 1,600 and 2,200 U.S. dollars/linear meter (1986 prices). The cross-section of this typical bridge is shown in Figure 8.

Significant savings in cost were achieved in Ecuador by using the low-cost bridges described in this paper. The savings in cost are given in Table 2, in which the relationships between the total bridge construction cost per linear meter, traffic loading, and type of bridge are shown. It is clearly indicated in Table 2 that the use of timber bridges significantly reduces the cost of construction. The average total cost of a one-lane timber bridge in Ecuador in 1984 and 1985 was approximately 400, 500, and 650 U.S. dollars/linear meter (1986 prices) for truckloads of 6, 10, and 24.5 tons (MS 13.5), respectively. This cost is approximately 20 to 30 percent of that of the two-lane, standard concrete bridge that was previously used in Ecuadoran rural regions (Figure 8b).

The concrete split-deck bridge is another economical water crossing. The average total construction cost of the multibeam bridge shown in Figure 10a varies between 450 and 750 U.S. dollars/linear meter, which is approximately 30 to 45 percent of that of a two-lane standard bridge. The higher cost values are related to heavier truck loads. This bridge type is recommended

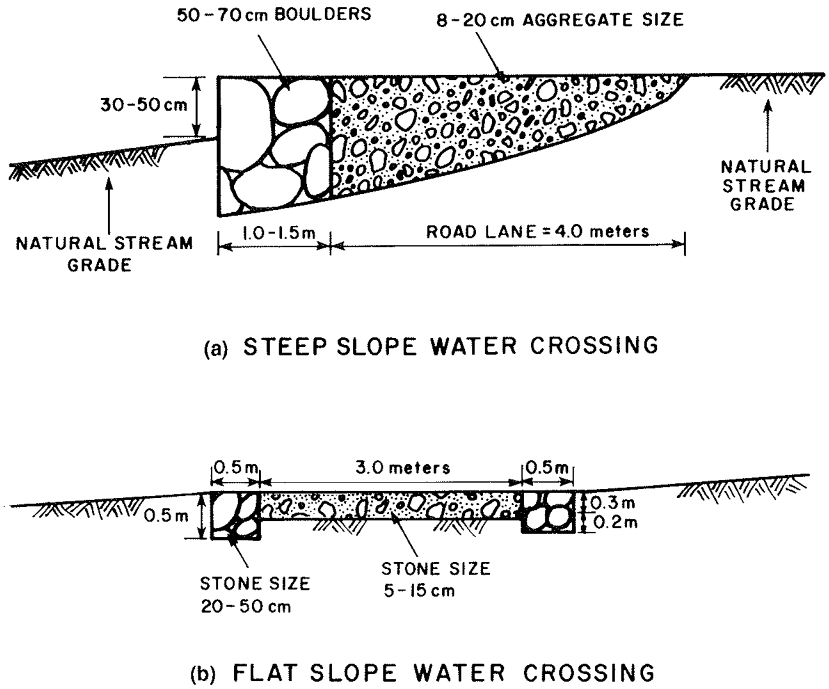


FIGURE 14 Simple ford cross-section (Ecuadoran mountainous zone).

TABLE 1 CONSTRUCTION COSTS OF RURAL BRIDGES IN ECUADOR IN 1984

Bridge width	Element	Economic cost x 10^3 (U.S. $/linear meter)
6.0 meters	Deck only	0.6 - 0.7
	Entire bridge	1.2 - 1.6
8.5 meters (Fig. 8.b)	Deck only	0.8 - 1.0
	Entire bridge	1.6 - 2.2

for short spans of about 8 m. The construction cost of the concrete split-deck bridge shown in Figures 10b and 10c usually varies between 400 and 900 U.S. dollars/linear meter for a truckload of 10 tons. This cost is approximately 28 to 40 percent of that of a standard two-lane bridge. The prestressed split-deck bridge is more economical when the single span of the bridge is over about 30 to 45 m.

Additional cost savings can be obtained by constructing a ford, as shown in Figures 5 and 14. The average construction cost of a one-lane ford was 50 to 120 U.S. dollars/linear meter. The variation in cost reflects the availability and cost of local materials and skilled labor in the vicinity of the project.

SUMMARY AND CONCLUSIONS

Investment in low-volume roads in developing countries can be economically justified only when very low-cost bridges and simple water crossings are used. Cost savings can be obtained by setting appropriate standards for the design elements of load, cross-sections, low-cost materials, and hydrologic and hydraulic design criteria, even though these criteria may appear to be substandard in the developed world. The following conclusions can be made.

Economic projection and traffic analysis indicate that truckloads of less than 6 to 10 metric tons are usually traveling along these roads. Therefore, most of the drainage structures are designed to carry 6 to 10 tons on two-axle, light vehicles. The AASHTO HS-15 or MS 13.5 loadings are used in the design of these bridges only when heavy traffic is expected from timber-producing regions or banana plantations. The AASHTO standard HS-20 live load cannot be economically justified for these low-volume roads.

The economic lifetime of a rural road in Ecuador was determined in 1984 and 1985 to be 17 years. All agricultural and other benefits can be achieved during this 17-year period. The investment in construction and maintenance costs can therefore be justified.

The traffic volume in Ecuadoran rural regions is often less than 100 vehicles per day; in fact, it is usually less than 20 to 50 vehicles per day. These low traffic volumes enable the use of graveled fords, such as those shown in Figures 5 and 14. The average construction cost of a one-lane ford was 50 to 120 U.S. dollars/linear meter. These timber bridges were found to be the most practical and economically justifiable bridges for simple spans of up to 17, 14, and 10 m, with 6-, 10-, and 24.5-ton truckloads, respectively.

The recommended storm period in the design of bridges on rural roads is 25 years. The recommended clearance between the maximum storm water level and the bridge should be 1 ft, unless the water velocity is very low. In cases in which the stream's ground slope is less than 0.5 percent, the maximum velocity is less than 10 ft/sec, and no accumulation of debris is expected, the water clearance could be reduced from 1.0 ft to 0.5 ft.

TABLE 2 COST COMPARISON OF LOW-COST BRIDGES (U.S. $1,000/linear meter)

	Bridge length (meters)				
Bridge type and loading	8 - 10	15	20 - 21	30	39 - 40
Timber bridge (Fig. 11)					
Load					
M6	.35-.45	.35-.45	.30-.40	.40-.55	.45-.60
M10	.40-.51	.43-.59	.45-.65	.45-.65	.54-.75
MS 13.5 (HS - 15)	.45-.62	.56-.77	.56-.77	.56-.80	.65-.90
Timber bridge (UNOID; Fig. 12)					
Load: MS 13.5	.62-.86	.46-.64	.43-.59	.48-.66	.46-.64
Multibeam (Fig. 10.a)					
Load					
M6	.40-.55	–	–	–	–
M10	.50-.68	–	–	–	–
M13.5	.62-.86	–	–	–	–
One - lane reinforced precast concrete split deck (Fig. 10b)					
Load: M10	.40-.60	.40-.60	.48-.66	.53-.73	.70-.97
Full-width deck (Fig. 9a)					
Load					
M10	.50-.68	.54-.75	.61-.84	.67-.92	.88-1.21
MS 13.5 (HS - 15)	.63-.86	.72-.99	.77-1.10	.85-1.17	.93-1.28
One - lane prestressed split deck (Fig. 10c)					
Load : M10	–	–	–	.60-.84	.60-.88
Full - width deck (Fig. 9b)					
Load : M13.5 (HS - 15)	–	–	–	.80-1.10	1.04-1.43

Timber bridges made of stringers and laminated decks (Figure 11) appear to be an economical and practical solution for low-cost water crossings. The total construction cost per linear meter of one-lane timber bridges in Ecuador in 1984 and 1985 was as follows:

Load	*$ U.S.*
6-ton truckloads (M6)	350 to 450
10-ton truckloads (M10)	400 to 650
24.5-ton truckloads (MS13.5)	450 to 750

These costs are in the range of 20 to 40 percent of an AASHTO standard, two-lane bridge design that was previously used in the rural regions.

One-lane, split-deck, reinforced concrete bridges (Figures 9 and 10) obviously have a longer life expectancy than timber bridges and they can still be considered as adequate, economical alternatives. The most practical alternatives are multibeam, reinforced, and prestressed beam decks, as shown in Figures 10a, 10b, and 10c, respectively. The average total costs of these bridges are about 450 to 800 U.S. dollars/linear meter. The split-deck, reinforced concrete simple span has been found to be the most practical and economically justifiable bridge type for simple spans of up to 30 m. Spans can reach 45 m when prestressed girders are used.

The total construction cost of a full-width, one-lane, precast concrete bridge (Figure 9a) is approximately 20 to 30 percent more expensive than the equivalent split-deck bridge shown in Figure 10. It should be noted that the full one-lane prestressed bridge is always designed to carry HS-15 truckloads, whereas the split-deck bridge is designed for a standard 10-ton truck (M10).

It can be concluded that with the judicious reduction of design standards of live loads, cross-sections, geometry, material specifications, and hydrologic and hydraulic considerations, the construction costs of water crossings can be significantly reduced. This also means that it is economically feasible to make improvements to low-volume rural roads.

REFERENCES

1. J. Greenstein and J. Bonjack. Socioeconomic Evaluation and Upgrading of Rural Roads in Agricultural Areas of Ecuador. In *Transportation Research Record 898*. TRB, National Research Council, Washington, D.C., 1983.
2. *Provincia de Chimborazo (Ecuador): Evaluacion Socio-Economica* (in Spanish). World Bank Loan 1881-EC MOP-BIRF. The World Bank, Washington, D.C., 1984.
3. *Manual de Estructura Para Puentes Debajo Costo* (in Spanish). (Structures manual for low-cost bridges). The World Bank, Washington, D.C., 1985.
4. J. Greenstein. Pavement Evaluation and Upgrading of Low-Cost Roads. In *Transportation Research Record 875*. TRB, National Research Council, Washington, D.C., 1982.
5. *Standard Specifications for Highway Bridges*. 13th ed. AASHTO, Washington, D.C., 1983.
6. *Manual for Timber Design for the Countries in the Andino Group (Columbia, Venezuela, Ecuador, Peru, Bolivia): The Development of Andino Projects in the Tropical Forest Zones*. Junta del Acuerdo de Cartagena-Bogota, Columbia, 1983.
7. *Timber Bridge Design*. ASCE, New York, 1985.
8. B. Buidar and J. Leslie. *Simplified Bridge Analysis*. McGraw-Hill Book Company, New York, 1985.
9. *Compendium 4: Transportation Technology Support for Developing Countries: Low-Cost Water Crossing*. TRB, National Research Council, Washington, D.C., 1979.

Use of Concrete Median (Jersey) Barriers as Ford Walls in Low Water Crossings

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The use of precast concrete median (Jersey) barriers as ford walls on low-volume roads is described. Ford walls are used on U.S. Forest Service roads to stabilize low water stream crossings. This is an acceptable practice on roads that have been temporarily closed for 1 or 2 hours as a result of flooding from sudden and intense storm runoff. The barriers are readily available, precast units that can be transported to the site and installed with conventional equipment that is used to maintain low-volume roads. Modified barriers with steel caps have also been used successfully to prevent erosion of the top of the concrete wall as a result of abrasive bedload movement during high water flows. Ford walls that were constructed with concrete median barriers have been used on hundreds of low water crossings in the desert and mountainous regions of the southwestern United States. These barriers have proved to be an efficient, low-cost alternative to conventional, cast-in-place concrete walls.

The U.S. Department of Agriculture, Forest Service, manages a network of approximately 300,000 mi of road on almost 200,000 million acres of land. These roads are needed to manage a variety of resources and activities, such as timber harvest, recreation, mining, forage, fire protection, and other forest-related activities.

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The Southwestern Region of the Forest Service manages approximately 46,500 mi of road in the states of Texas, Oklahoma, New Mexico, and Arizona. About 70 percent of these roads are of a low standard; most are single-lane roads with dirt or pit-run surfacing and an average daily traffic count of less than 50.

The terrain in the Southwest varies from low Sonoran desert to mountains that are more than 10,000 ft high. Annual rainfall varies from 5 in in the desert to 50 in in the upper pine and alpine forests. Sudden, intense rainstorms are common during the rainy season in July and August. Stream beds that are normally dry become raging torrents within a matter of minutes. These storms often cause injuries and occasionally cause deaths.

A wide range of soil types exists in the Southwest. Much of the soil is composed of highly erodable sandy clays, decomposed granite, and plastic clays. Many roads are impassable for short times during storm runoff because the crossings are flooded and road surfaces are soft and slippery. Good drainage is the key to reducing repair and maintenance expenditures.

THE PROBLEM

The Southwestern Region of the Forest Service has experienced seven major storms since 1972 that have caused over $25 million in damage to roads. Much of the damage occurred at low water crossings. Because of budget restrictions and low traffic counts, drainage structures such as large culverts and bridges are the exception instead of the rule.