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Field Notes

ENERGY PREDICTION AND CONTROL OF ROAD DAMAGE

CONTRACTOR-DESIGNED BRIDGES —COST SAVINGS IN ALASKA

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ENERGY PREDICTION AND CONTROL OF ROAD DAMAGE

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The Forest Service manages one of the largest (in terms of both mileage and dollars) road systems in the world. If our annual investment in Forest Service road maintenance could be reduced by just 1 percent, a savings of nearly $1 million could be realized.[1] To reduce road maintenance, we must first reduce road damage; the effects of traffic, weather, moisture, and maintenance vehicles and practices must be measured in terms of the damage they cause, and then weighed in a long-term investment balance.

We can define a road in a way that can be related to subsequent measures of damage to it: A road is, simply, a useful path of lowered rolling resistance . . . all other definitions are secondary. A wheelbarrow is pushed along a plank for this simple reason: Once off the plank, pushing the wheelbarrow becomes extremely difficult.

Road damage causes increased rolling resistance. If road values and road damage are defined and measured in terms of rolling resistance, then they are being measured in equivalent units of energy. These energy units can measure the destructive processes that cause road damage. Other measures of destruction (such as how many vehicles passed, or how many times any event occurred) can have meaning only if each event imparts the same amount of energy. Otherwise, the events are not measures of the amount of destruction, since they cannot be summed for accumulative evaluations.

The value of an energy comparison is that it can measure causes and effects separately or together; the energy does not have to be called out by that name, it has only to be contained in the unit of measure. For example: A pavement slab can take a number of flexural stress reversals before it cracks. The number of reversals depends upon how hard and how far it is bent and, therefore, upon how much energy is imparted per cycle. This unit of measure is given by the area of the hystersis loop generated during flexure.

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[1] *Howlett, Myles R., Keynote address of "Workshop on Lessening Energy Waste in the Road-Tire-Vehicle-Driver System," 1976. Proceedings available from University of California, Berkeley, Institute of Transportation Studies.*

In practice, we measure the bending of the slab on its elastic foundation by the axle load from the elastic properties inferred by a Benkleman beam, the California Bearing Ratio (CBR), or a plate bearing test; thus, a specific kind of failure is related to a specific input. This is sound engineering, and I respect it because a plausible model is used to relate dominant causes and effects; further, statistical methods are used to measure the effects of random elements not included in the model.

Since statistical theory is based upon random behavior, the presence of a hidden determinate law in a statistical study means that increasing the sample size with ever-larger experiments will not bring increased accuracy. Not until the statistical model includes the determinate law (as closely as it can be formed from dimensional analysis or other intuitive engineering methods) will accuracy be increased.

I object, therefore, when the respected CBR test is used as a correlated parameter to predict gravel loosening, which occurs from shear--<u>not</u> from flexure. This has gone on for 30 years and can go on for another 30 years, but it is still invalid. It will never give a measurable answer--just more correlations that don't become better with larger sample sizes.

Determinate relations cannot be erased from a study by ignoring them. We can, however, generalize so that the effects can be related to causes by several alternate paths, without always having to know, <u>a priori</u>, which path is correct. Instead of debating whether flexure or shear causes a specific road damage, we can relate the damage to the energy wasted by both of these, and escape the dilemma.

To investigate any phenomenon scientifically, two distinct practical steps have to be taken:

1. Isolate the system to determine what goes in and what comes out.

2. Correlate what goes in and what comes out with what changes have taken place within the system.

In a tire/road system, only energy is going in or coming out. We cannot find what goes in and what comes out from inside the system--these must be observed at its boundary. Energy to sustain tire and road rolling resistance and soil slip can be measured for a vehicle and <u>separated</u> into tire energy and road energy at the tire/road boundary. Only interface slip between the tire and gravel wears the tire. The remaining, or "loose slip," energy is imparted to lower layers of gravel, and is the cause of road deterioration by "traffic damage."

To explain the slip concept:[2] If we bear down on a rubber eraser so that 5 pounds (6.08 troy pounds) of slip force are needed to move it, and it is moved 2 feet (0.61 meter), we expend 5 x 2--or 10 foot-pounds (1.38 kilogram-meters)--of slip energy. If we double either the force or the distance, we double the slip energy and, consequently, also the amount of rubber eraser and paper that is worn off in the process.

The changes take place where the slip takes place (at the rubber/paper or tire/road interface) and, in the case of gravel roads, also in the lower layers of gravel beneath the tire. Whether a tire slips "x" ft/mi longitudinally or sideways, the tire and road materials show no difference in behavior in either the eraser/paper or tire/road experiments--slip energy has no directional bias in its effects.

As to the second investigative step, one has to look inside the road system to find what the energy input does. If the road is too dry, even a "pure" rolling tire will loosen it, and the changes in rolling resistance energy will measure this damage. If the water content is near the Proctor condition, the rolling tire will compact the gravel, and this change is described by similar standard American Association of State Highway Officials tests for compaction energy. If we apply power or brakes to induce slip, we can undo the compactive effects of rolling.

The effects of rolling and slipping are mutually opposed and, for any given Proctor condition of moisture and compaction, a ratio, μ, of tractive force to normal compactive force will define the net effect (compactive or loosening) of the wheel upon the road surface. A neutral μ ratio will vary with the Proctor condition. The important point is: If the net effect of the tractive wheel on the road surface is a loosening, the next tractive wheel will slip more, and surface loosening will continue and accelerate.

We can tolerate normal road deterioration if we avoid extremes. Gravel losses do not occur on tight roads, since they behave like pavements. Gravel loss is not the same for each passing vehicle; it occurs drastically, if it occurs at all, and it occurs only when the road is too loose to sustain the traffic. (I am ignoring aggressive tires that throw gravel, and grader operators who blade gravel off the road--these are separate problems.)

The amount of rolling resistance and slip energy expended in the soil aggregate can be used to macromeasure the road's surface

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[2] *Della-Moretta, Leonard, "Relating Operational Variables to Tire Wear" (paper presented at ISTVS Regional Meeting, Carson City, Nevada, 1974). Available from Forest Service Equipment Development Center, San Dimas, California.*

deterioration. When the deterioration from one road condition to another is correlated, the slip energy input can also predict the further deterioration from an expected load of traffic. Road maintenance could be correlated with traffic load and character to prevent loss of surfacing material when the road surface is too loose to sustain high traffic stresses.

The game is <u>not</u> over because we cannot effectively control the traffic. We can roll the road, water it, and then retain the water by using stabilizing agents and by using daytime blade maintenance to prevent further drying of the road. The traffic that insists on using the road when its moisture is too low should contribute dollars to pay for the damage caused; also, the road can be recompacted after a rain by suitable rolling or traffic. (Since gravel losses are either drastic or not at all, the payoffs are worth considering.)

As long as we consider only axle loads and ignore energy inputs, all traffic will be classified as damaging; the alternate loosening and healing effects of traffic will be ignored; and none of the protective measures will be carried out. Roads will be bladed when relatively dry, causing them to dry out further. These dried-out, dusty roads will be left to be compacted by traffic, rather than being rolled after a rain to achieve proper healing.

As long as we ignore shear energies, we will not be able to control traffic, because we will have no valid method for predicting or measuring the amount of damage that can be inflicted when the road is unfit for such traffic. If we define a road's condition in energy terms, we can describe it by a number that is verifiable by others, and tangible to bargainers.

As long as we can measure how much energy is being wasted, we do not need to become lost in debate over the detailed mechanics of the waste and damage processes. The fact that waste energy and changes in material properties show good correlations in practically all natural processes (when properly defined, all these processes are energy accountable) is a good basis for solving our road maintenance problems by putting energy mechanics to work.

CONTRACTOR-DESIGNED BRIDGES PRODUCE SIGNIFICANT COST SAVINGS FOR THE ALASKA REGION

Frank W. Muchmore, P.E.
Regional Structural Engineer
R-10

Traditionally, the term "Alaska" often conjures visions of ice and snow, polar and Kodiak bears, moose and caribou, Eskimos, gold mines, pipelines, high wages, and higher prices. The oil pipeline is finished. Most of the gold mines have closed down, mainly because of excessively high operating costs. However, all construction projects throughout Alaska share one image: Extremely high costs, when compared to similar projects in the "lower 48" states. Forest Service bridge construction projects are no exception to this image.

FOREST SERVICE TRANSPORTATION SYSTEM

The Forest Service transportation system in southeast Alaska is unique in that it is located primarily on the islands of the Alexander Archipelago, leaving this area of the Region with no interconnecting land transportation network. Development of a transportation system in this island environment presents many challenges; logistical planning becomes critical, and the difficulty in obtaining materials, tools, and equipment that would normally be taken for granted "down below" can, and often does, become a logistical nightmare.

For example, a 50-cent item may take days to get and cost hundreds of dollars in charter plane fares to transport to the worksite. In most cases, heavy equipment and materials must be barged from island to island, off-loaded at low tide, and reloaded on trucks. Any other contact with "civilization" is limited to radio, float plane, or weekly mail boat service.

The Alaska Region's permanent (long-term) road bridges are constructed as both single-lane and double-lane structures. Most bridges span salmon-spawning and -rearing streams and require special precautions against streambed disturbance during construction. All of these conditions contribute to the high cost of bridge construction projects in Alaska.

PROCEDURES USED

Over the past several years, the cost of constructing permanent road bridges in southeast Alaska has been between $85 and $140 per square foot ($914.96 and $1,506.99 per square meter) of deck area. These high costs prompted the Forest Service to investigate alternative methods of bridge design and construction.

The Forest Service does not maintain a structural design staff in the Alaska Region. Bridge designs and drawings are usually prepared by design groups in other Forest Service Regions, or by other Federal agencies that are often unfamiliar with the equipment, materials, weather, logistics, and other construction parameters unique to southeast Alaska. Several years or more may elapse between the completion of the design and the start of construction. By the time contracts are advertised, continually changing market conditions often make it economically impractical to use previously selected bridge material. Development of a design procedure that could take advantage of current construction materials market conditions as well as a particular contractor's methods, equipment, and operations should yield significant savings. In addition, any experience that contractors may already have in bridge work in this unique southeast Alaska environment may enable them to produce both designs and cost estimates based on similar projects already completed. Taking these considerations into account, the Region-10 Engineering Staff proposed the adoption of the "turn-key" concept for selected bridge projects. This calls for contractor responsibility for both design (by a registered professional engineer) and construction of the bridge structure.

DESIGN SPECIFICATIONS

Specifications were prepared that allowed contractors to submit a bid on their own design proposal (Alternative B) as well as the Government design (Alternative A). The design specification was modeled on specification requirements for the engagement of consulting engineering bridge design services. The basic requirements were:

1. Conformance to the AASHTO Standard Specifications for Highway Bridges, except as modified in the design specification;

2. Design by a registered professional engineer; and

3. Adherence to minimum clearance, span, and other site considerations.

A topographic site map and a foundation investigation report are included in the contract documents. At the time of the bid opening, the contractor is only required to submit a rough outline of his/her proposal; after acceptance of the bid offer by the Forest Service but prior to performing any work, the contractor is required to submit a complete set of design calculations, detail drawings, and construction specifications for approval. In practice, this procedure has worked quite well, although approval of designs has been delayed several times when the submitted design did not meet all the AASHTO and contract criteria, and had to be returned to the contractor several times for correction and resubmission. In spite of this, no serious delays have been experienced.

A lump-sum bid item was used for design and construction of the structure itself, including approach earthwork and roadway construction items when these items are not included as part of a large road construction job.

CONTRACTOR-DESIGNED PROJECTS

Pat's Creek Bridge

This procedure was first implemented in May 1975 for construction of the Pat's Creek Bridge on Wrangell Island, located south of the southeast Alaska community of Wrangell (fig. 1). The Government's Alternative A design called for three 3 1/2-foot-deep (1.07-meter-deep) steel plate girders for the 73-foot (22.25-meter) simple span, with 15-foot (4.57-meter) cantilevered side spans and a cast-in-place concrete deck. The low bidder's Alternative B design specified five 12 1/4- by 51-inch (0.311- by 1.30-meter) treated, glu-laminated stringers, also with a cast-in-place concrete deck. The low bid for Alternative B, which included the design cost, was 6 percent less than the low bid for Alternative A (table 1). The contractor obviously took advantage of a less costly structural system, i.e., glu-laminated girders, enabling the contractor to submit a lower bid than for a steel girder bridge.

Harris River and Fubar Creek Bridges

Steel plate girder structures were designed by the Government for bridges over the Harris River and Fubar Creek, both of which are located on Prince of Wales Island west of Ketchikan (figs. 2 and 3). The center span and cantilevered side spans were to be topped by a treated, glu-laminated wood deck. The low bid for the contractor-designed Alternative B consisted of six precast-concrete, post-tensioned bulb T-girders, 5 1/2-feet (1.68-meters) deep for the 125-foot- (38.1-meter-) long Harris River Bridge, and 4 1/2-feet (1.37-meters) deep for the shorter 100-foot (30.48-meter) span at Fubar Creek. Both Government and contractor designs utilized steel sheetpile abutments and steel H-pile foundations. The low bid for Alternative B was 3 percent less than the low bid for Alternative A (table 1). Due to the lack of heavy lifting equipment in southeast Alaska, one would expect heavy concrete girders to be prohibitively

Figure 1.--Pat's Creek Bridge, Stikine Area, Tongass National Forest.

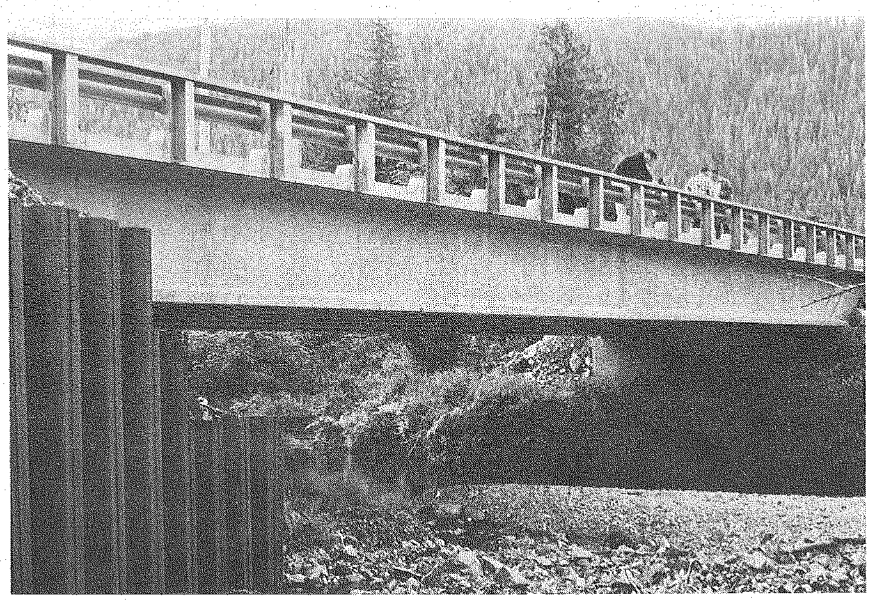

Figure 2.--Harris River Bridge, Ketchikan Area, Tongass National Forest.

expensive. It normally costs in excess of $50,000 to mobilize a 100-ton (90.72-metric ton) or larger crane in southeast Alaska, which must be barged a thousand miles (1,609 kilometers) each way from Seattle. However, the low bidder happened to have a 110-ton

TABLE 1. *COMPARISON OF BIDS FOR FOUR PROJECTS (SIX BRIDGES)*

Project	High Bid[1]	Average of All Bids[1]	Low Bid[1]
Pat's Creek Bridge			
Alt. A--Government Design	401.2	350.4	282.0
Alt. B--Contractor Design	378.6	320.8	264.4
Percent Difference	5.6%	8.5%	6.2%
Harris River - Fubar Creek Bridges			
Alt. A--Government Design	1,489.3	1,371.4	1,241.9
Alt. B--Contractor Design	1,411.3	1,298.9	1,204.0
Percent Difference	5.2%	5.3%	3.1%
Gravel Creek - Newlunberry Creek Bridges			
Alt. A--Government Design	522.6	383.4	315.4
Alt. B--Contractor Design	385.0	345.0	289.0
Percent Difference	26.3%	10.0%	8.4%
Sarkar Rapids Bridge			
Alt. A--Government Design	709.1	664.4	640.1
Alt. B--Contractor Design	657.1	595.5	533.9
Percent Difference	7.3%	10.4%	16.6%

[1] *In thousands of dollars; rounded off.*

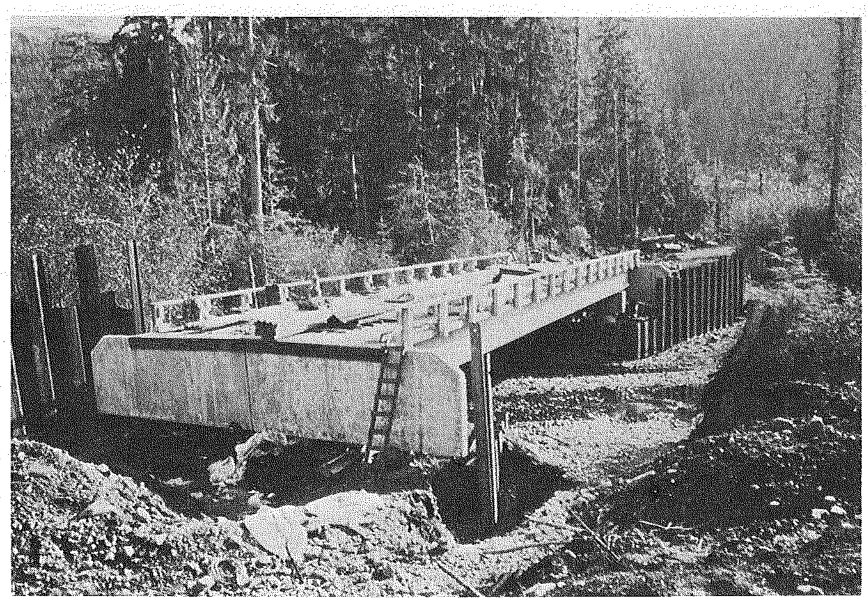

Figure 3.--Fubar Creek Bridge, Ketchikan Area, Tongass National Forest.

(99.79-metric ton) crane and earthmoving equipment on a state job adjacent to the proposed Forest Service project. Therefore, no equipment mobilization cost would be incurred, and thus the reason for the low bid.

Gravel Creek and Newlunberry Creek Bridges

In the case of the drainage structures over Gravel and Newlunberry Creeks on Prince of Wales Island (figs. 4 and 5), the Alternative A Government proposal consisted of construction of a Government-designed, open-bottom arch at Newlunberry Creek, and a contractor-designed and -constructed structure at the Gravel Creek site. Alternative B left design and construction responsibility for both structures with the contractor. The low contractor bid was for Alternative B, with the design for Newlunberry Creek consisting of five 14-inch by 52-inch by 52-foot- (0.36-meter by 1.32-meter by 15.85-meter-) long treated, glu-laminated stringers with a treated, glu-laminated wood deck (the Weyerhauser Panelized Bridge System) supported by a steel pile cap bearing on steel H-piles. The Gravel Creek Bridge design shared the same features, using slightly larger glu-laminated stringers due to a longer span of 64 feet (19.51 meters). The low bid Alternative B for the Gravel and Newlunberry Creek Bridges was 8 percent less than the low bid for Alternative A (table 1). Surprisingly a 52-foot (15.85-meter), glu-laminated bridge was less costly than a 25-foot (7.62-meter) span, open-bottom arch.

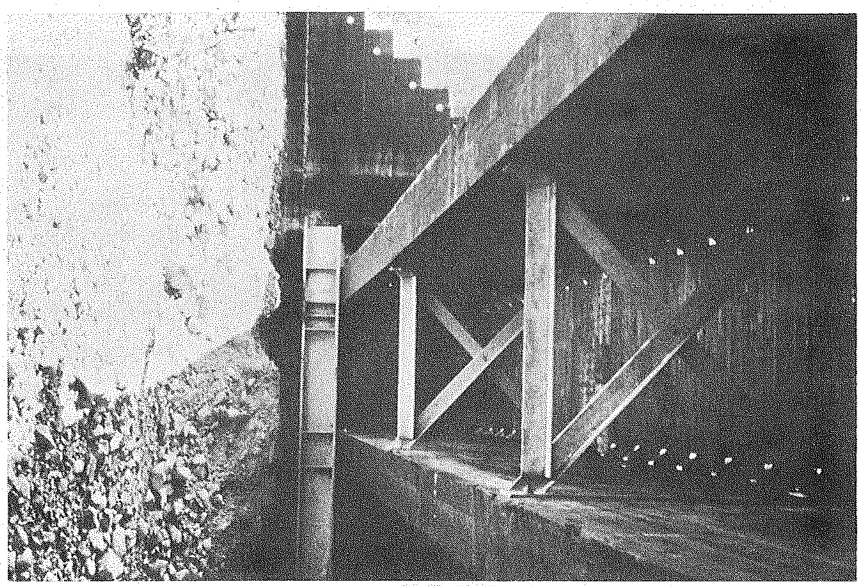

Figure 4.--Gravel Creek Bridge, Ketchikan Area, Tongass National Forest.

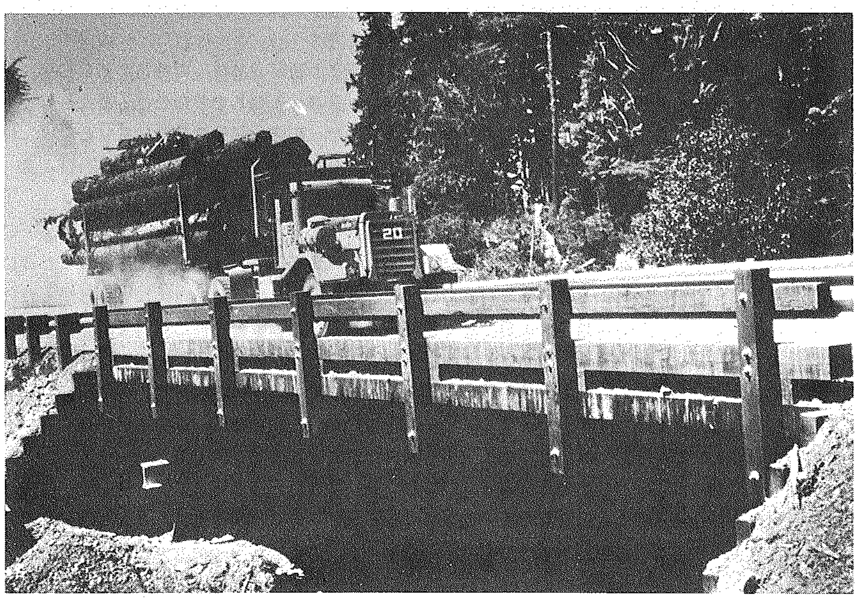

Figure 5.--Newlunberry Creek Bridge, Ketchikan Area, Tongass National Forest.

Sarkar Rapids Bridge

The Sarkar Rapids Bridge, located on the west side of Prince of Wales Island (fig. 6), was initially advertised with a Government

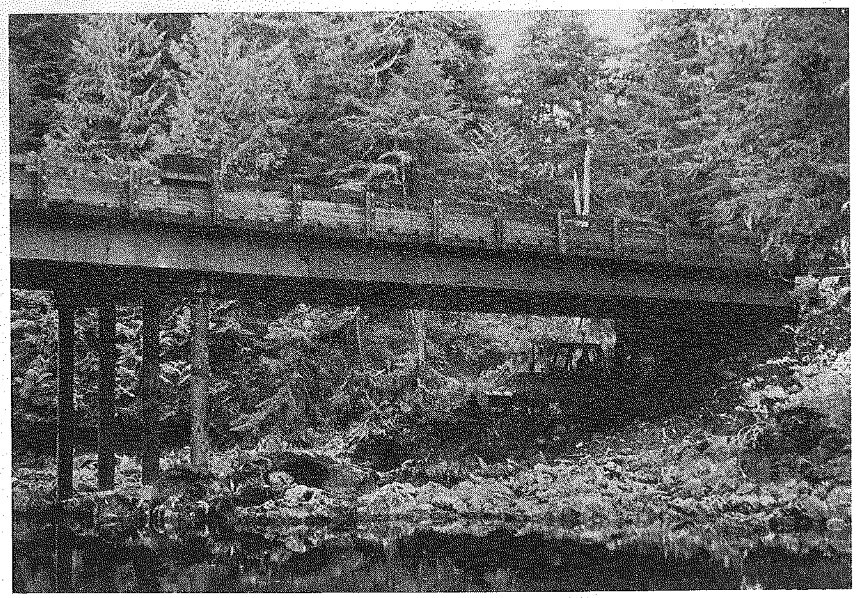

Figure 6.--Sarkar Rapids Bridge, Ketchikan Area, Tongass National Forest.

design calling for six precast, prestressed concrete bulb T-girders, with precast concrete abutments and an intermediate pier resting on cast-in-place concrete footings. Due to excessively high bids received for this design, the bids were rejected, and a new package was advertised adding the contractor design option. This time the low bid, which was for a contractor-designed bridge, came in well under the bids for the Government design. The contractor design called for steel box girders and a treated, glu-laminated, wood panel deck. Abutment and intermediate pier bents consisted of steel pipe columns, socketed into rock, with wide flange steel pile caps. The low bid for Alternative B was 17 percent below the low bid for Alternative A (table 1). There was no convenient large crane available for this job; undoubtedly, this explains the higher bid price for the prestressed concrete structure. In addition, a very innovative box girder design resulted in girders only 42 inches (1.07 meters) deep for the 80-foot (24.38-meter) spans and 100-ton truck loading.

BID ANALYSIS

All of the design proposals accepted under the contractor-designed options have been prepared by consulting engineering firms (A&E). Bid prices are difficult to compare between projects due to the varying amounts of approach roadwork that have been included in the lump-sum bid items. However, on each project, the same amount of roadwork was involved for the Government-furnished design option as for the contractor-designed option. In all cases, the Government-designed bridge bid items were in the traditional pay-item format with bid prices for each item of work, while the contractor-designed bridge bid items were in lump-sum format. Table 2 shows the relationship of the low bids on each project. The low bidder on the project did not necessarily have the lowest bid on the bridge-only items, nor the high bidder the highest. Obviously, unbalanced pricing of individual items was frequently used, rendering an analysis of the bridge-only items correspondingly unreliable. In Government contracting, the bottom-line figure is the deciding factor in awarding the contract. As a result of the unbalanced bidding, only the trends exhibited by the average of all bids are considered here. Table 2 summarizes the savings realized. Net saving shown is the total difference in bid prices less the estimated cost of the unused Government design.

VALUE ENGINEERING INCENTIVE

In an attempt to further reduce costs, the fourth project, Sarkar Rapids Bridge, included a value engineering incentive clause.

This clause was a modification of the basic clause used by the United States Army Corps of Engineers. Simply stated, it allows the contractor, after award of the contract, to submit cost-reducing proposals. If accepted by the Government, the net cost reduction is shared with the contractor. The net savings from the first two accepted proposals under each contract are shared at a 50-50 ratio; the next two, at a 55-45 ratio; and subsequently, at a 60-40 ratio, with the larger share going to the contractor.

This incentive clause has been included in several other road construction contracts; however, no proposals have been submitted nor savings realized to date.

SUMMARY

The savings realized on the first four projects have been significant. A net dollar savings of $137,100 resulted after deduction of the design costs of the unused Government designs. The trend shows an average net saving of about $9.00 per square foot ($96.88 per square meter) of deck surface, or approximately 11 percent when contractor-furnished designs were used. Additional projects have been advertised for only contractor-designed bridges and no alternative Government design. Bids received have been comparable to those described above.

Region-10's experience with contractor-designed projects has shown the significant savings have been realized by the use of contractor-furnished designs. However, remember:

1. Region-10 has not had a bridge design staff;

TABLE 2. COMPARISON OF LOW BIDS--FOUR PROJECTS

Date	Project	Low Bids[1]		Percentage Difference	Dollar Difference[1]	Estimated Cost of Government Design[1]	Net Savings[1] (Dollar Difference, Less Government Design Cost)
		Government Design	Contractor Design				
5/75	Pat's Creek Bridge	282.0	264.4	6.2	17.6	11.0	6.6
6/75	Hydaburg Road (Harris River-Fubar Creek Bridges)	1,241.9	1,204.0	3.1	37.9	25.0	12.9
7/76	Gravel Creek Newlunberry Creek Bridges	315.4	289.0	8.4	26.4	5.0	21.4
8/77	Sarkar Rapids Bridge	640.1	533.9	16.6	106.2	10.0	96.2

[1] *In thousands of dollars; rounded off.*

2. Logistics and high mobilization costs often make "lower 48" methods and procedures uneconomical for Region-10 conditions; and

3. This has not been a panacea or cure-all for all of Region-10's bridge problems and was not intended as such. It has, however, been successfully used to supplement the "normal" procedures for bridge construction.

THE HOBO ENGINEER

Comments by
Clifford Miller
Regional Engineer
R-4

This poem was framed and hanging in the Regional Engineer's office in Ogden when I arrived to follow behind Jim Usher. I don't know if Jim inherited it from Minor Huskley or not. The paper on the back of the frame is brittle, and when I moved it recently a piece fell off revealing the author and date.

The poem was written by two of Region-4's engineers, Frank Allen and Ted Keller, in 1937. Frank was working for the Forest Service as early as 1929; both men have now "tied up to the Great Unknown." The way of life expressed in the poem that our predecessors lived still expresses some dreams of today.

The Hobo Engineer

I sometimes think I'll quit this life
And settle down and get a wife, by Jove!
Sometimes I think that I would love
To have some place I could call home
And settle down, no more to roam--
But Hell, that very thing I've tried
And found myself dissatisfied.
I've often tried to settle down
To office work and live in town
And act like civilized folks do;
Take in the shows and dances too.
But I'd no more than get a start
Till "wanderlust" would seize my heart
And in my night dreams I would see
The great white silence calling me,
And at the chance I'd never fail
To drop it all and hit the trail

Back to the solitudes again
With transit, level, rod and chain
To lead the simple life once more,
And do the same thing o'er and o'er
Day after day and week after week.
Sometimes we go to town to seek
A little fun and sometimes--well,
Sometimes we raise a little hell;
(We don't mean to, but then you see
When we've been out two months or three
In silent places where the face
Of white man seems so out of place).
Well, when we hit the "Great White Way"
Our joyful spirits get full sway;
We try to crowd into one night
The joys of many months. 'Taint right.
Well maybe not, 'tis not for me
To shape our final destiny.
But when our last survey is done
And tie'd up to the Great Unknown,
And to the Chief our records brought
Of lonely work with danger fraught,
Of hardships cheerfully endured
That best results might be secured,
Against all this our little sprees
Will seem as ponds compared to seas.
And the Angels will decide
There's a balance on the credit side,
And God, I think, will drop a tear
And bless "The Hobo Engineer."

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