United States
Department of
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Forest Service

Engineering Staff

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Engineering Field Notes

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Engineering Technical Information System

1995 *Engineering Field Notes* Article Awards

It's that time of year again! Time to let us know which articles you found to be most informative, beneficial, and interesting; which articles helped your office save money; and which articles helped you accomplish your work most effectively and efficiently.

Although only three issues were printed in 1995, the quality and diversity of the articles did not diminish. We shared information in many diverse fields—geometronics, ecosystem roads management, facilities and other structures, and geotextiles. *Engineering Field Notes* (EFN) continues to provide a way for Forest Service engineers at all levels and from all Regions to share their knowledge and experience. We believe that this sharing is vital to doing more with less, and we applaud each of our authors.

After selecting your three favorite articles, please complete the rating sheet on the following page. Rate the three articles from 1 (best) to 3 (third best). If you feel that an article has helped or will help the Forest Service save money or other resources, please let us know. Remember, it is one person/one vote—so your vote counts!

After you have voted, cut out the rating sheet along the dotted line, fold and staple it closed, and mail it back to us at EFN. (For your vote to count, we must receive your rating sheet by May 1, 1996.)

Contests aside, we would like to thank each of our EFN authors, as well as our readers, who made 1995 a great year. Each of you deserves a pat on the back for helping to foster an environment where information and experience are viewed as valuable resources and are shared accordingly.

We encourage you to start thinking of articles for 1996. Why not share your experiences through EFN in 1996?

1995 *Engineering Field Notes* Awards

ARTICLE	AUTHOR	CHOICE (1, 2, 3)	$ SAVED (✓)
January–April			
Development of Cushion Aggregate on Native Surface Roads by Use of the Roto Trimmer	Northrup, Jim L.	______	______
Solving Dry Problems with Geotextiles	Standing, Paul and Jenner, Steve	______	______
The Spelunker's Delight: Cave Surveying Made Easy	Moll, Jeffry E., Harrison, Michael, Turner, Ransom, and Sutton, Warren F.	______	______
May–August			
Energy-Efficient Lighting System Installed in USDA Jamie L. Whitten Federal Building	Murtagh, Ed	______	______
Forest Service Conversion to Metric Measurement	Coghlan, Gerald T.	______	______
Improving Culvert Entrances to Increase Flow Capacity	Grimaldi, Carol	______	______
Stabilization and Standard and Nonstandard Stabilizers: Road Operations and Maintenance Workshop (Colorado Springs, May 1995)	Bolander, Pete	______	______
The Technology and Development Program: A Blueprint for Success	Simila, Keith	______	______
September–December			
Geographic vs. Cartographic	Napier, Barry	______	______
North American Datums—NAD27 and NAD83	Napier, Barry	______	______
Solar-Powered Fan Improves Vault Toilet Venting	McCutcheon, John D. and Taylor, Nancy	______	______

TEAR ALONG THIS LINE →

COMMENTS: ____

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Name ______________________________
(OPTIONAL)

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A Course Filter Method for Determining the Economic Feasibility of Helicopter Yarding

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Abstract

Helicopter logging is the most expensive and potentially hazardous method of logging. However, because it can also be the most efficient and environmentally sensitive method used in logging an area, we have seen an increase in the number of National Environmental Policy Act (NEPA) decisions in Region 1 that include helicopter yarding. Unfortunately, a downturn in the log market has resulted in an increase in the number of advertised sales, many of which required helicopter yarding, that received no bids.

These factors make it increasingly important to determine economic feasibility for helicopter projects early in the planning process. This paper provides a course filter screen approach for gates 1 and 2 in the National Timber Sale Planning Process gate system. This approach is designed to develop a tool for identifying economically infeasible alternatives for use by sale planners and/or interdisciplinary teams.

Use of this tool would allow early identification of infeasible alternatives and reduce the time and funds spent in the NEPA process on planning, developing, and analyzing. It would also allow the limited funding available to be directed toward projects with a higher probability of successful implementation.

This article utilizes a course filter process based upon a review of the computer program HELIPACE, versions 2.01 and 2.5, written by the Aerial Forest Management Foundation. This review identified three significant variables with the greatest affect on helicopter stump-to-truck costs (fell-buck, yard, and load). These variables, by order of significance, are: load factor (measure of efficiency in achieving turn weight), flight distance (adjusted for grade and any obstructing topography features), and resulting canopy closure over the felled logs (not necessarily overall residual stand canopy closure).

The course filter method is intended for use during gate 1 (Position Statement) and gate 2 (Alternative Development), and can be used to answer the following questions:

1. How far can one afford to yard using a helicopter?

2. Are the silvicultural/fuel treatments compatible with the helicopter capabilities?

3. Are the costs of helicopter logging reasonable, assuming the value of the products being considered?

HELIPACE Model Review

The authors performed a sensitivity analysis using repeated runs on the computer program HELIPACE, versions 2.01 and 2.5. The analysis examined the significance of different variables to determine their effect on helicopter stump-to-truck costs. Three variables were found to have the greatest effect: payload (load factor), flight distance, and canopy closure over the logs.

Payload

Payload is the external load that helicopters that are constructed or modified for logging can safely lift at a specified elevation and temperature. Payload is a significant variable, as defined indirectly by the variable referred to as load factor in the HELIPACE model. Load factor is a measure of efficiency for achieving turns at or near optimal target weight (payload). As load factor decreases, yarding cost per thousand board feet (Mbf) increases. More simply stated, the lower the payload per turn, the higher the cost per Mbf.

Flight Distance

Flight distance was analyzed for a yarding distance ranging from 0 to 36,000 feet to reflect conditions that have been encountered on past sales in Region 1. As expected, cost per Mbf increased at a linear rate as flight distance increased. The increase in cost is tied directly to the increase in flight time. Economic viability beyond approximately 20,000 feet is very questionable; therefore, this assessment chose to graphically display flight distances only from 0 to 20,000 or 25,000 feet, depending on the type of helicopter (Bell 204 or Boeing Vertol (BV) 107).

Canopy Closure

Canopy closure is an estimate of the percentage of area occupied by the crowns (canopy) of the residual trees over the logs to be yarded. It is not the remaining canopy closure of the entire stand, unless there is uniform felling across the unit and uniform distribution of residual trees. Canopy closure influences the number of turns that are obstructed during the hooking and lifting operation, that is, the number of turns that cannot meet the design turn load weight because the hookers cannot gather an adequate number of logs at a given location, which influences both the total turn time and the number of turns required to move a specific amount of material. As remaining canopy closure over the logs increases, turn weights decrease and turn times increase. In this assessment, canopy closures over the logs in excess of 75 percent were considered operationally infeasible for reasons of safety and in accordance with standard industry practice.

Cost Versus Value Comparison

Before determining how logging costs affect the economic viability of a project sale, one must review the proposed timber harvest from a safety standpoint and determine whether it should be pursued. Then, one must ask the following question:

> *Is this logging project physically feasible and operationally safe, recognizing the capabilities of the design ship to hook, lift, and yard the products in question?*

Only when the answer is "yes" should one proceed to the next question, which may seem trivial, but is important, especially in high-market conditions where it seems as if one can sell anything offered:

> *Are the products under assessment marketable, that is, do they have value? If so, will that value be present under all market conditions?*

Total sale value must exceed total sale cost to be economically feasible and to reasonably expect purchasers to bid on the sale. To determine whether this is the case, the following comparison should be made:

Product Value – [Sale Costs + Haul Cost] = Available Stump-to-Truck Cost

Product value can be estimated by determining product type, product quantity, and the product's potential destination for processing. Inquiries can be made of potential bidders to produce an idea of the delivered product value. Delivered product value should reflect an average and be independent of the logging method.

Caution: In deriving a delivered product value, be sure that there is a mutual understanding of the specifications of the products being discussed. Product value can vary widely, depending upon how the raw material is utilized. For example, a felled white pine might be used for manufacture of boards, chips, or house logs. Standing in the forest, the white pine is raw material, but each of the various uses will have a significantly different market value, which affects the relative economic viability of a helicopter sale and how far white pine could be viably flown.

Sale costs include, but are not limited to, costs the purchaser would be required to pay, such as an expected advertised rate for stumpage, brush disposal, road maintenance deposits, and estimated ineffective road credits for road construction. An estimate of these costs can be obtained from similar local sales.

Haul cost should be estimated for the products, taking into consideration factors such as the availability of one-way paved and unpaved roads, feasible travel speed, and traffic conditions. An estimate can be made using existing tables or similar local sales.

Available stump-to-truck cost is derived by subtracting sale costs and haul cost from the product value. This cost is then compared to the stump-to-truck cost derived from the appropriate graph, as outlined in the following section.

Graph Method

The graphs shown in figures 1 through 6 at the end of this article were constructed to assist the user in determining how far a product can be flown or whether stump-to-truck costs can be recovered using a proposed alternative, given value, sale costs, and distance. Utilize these graphs as follows:

Gate 1

Assume that the objective is to determine how far an identified product can be viably flown.

Step 1: Determine average delivered product value (dollars per unit).

Step 2: Estimate advertised rate plus brush disposal, road maintenance, road construction, and any additional required deposits (dollars per unit).

Step 3: Estimate haul cost from center of proposed project to nearest identified product manufacturing site (dollars per unit).

Step 4: Determine available stump-to-truck cost (step 1 – [step 2 + step 3]).

Step 5: Determine what type of helicopter available in your area would meet your needs (Bell 204 or BV 107).

Step 6: Choose the silvicultural prescription that best describes the proposed treatment (regeneration, salvage/improvement, or intermediate/thinning).

Step 7: Decide what percentage of the target payload weight that you think will, on average, be achieved (we recommend determining this value through a visit to the proposed treatment areas). Following is a suggested range of values for each silvicultural prescription:

Silvicultural Prescription	*Suggested Load Factor Range*
Regeneration	0.75–1.0
Salvage/improvement	0.65–0.85
Intermediate/thinning	0.50–0.75

Step 8: Select the appropriate graph from figures 1 through 6. Find your stump-to-truck value on the y-axis, move horizontally to the intersect point for the chosen load factor, move vertically down to the x-axis, and read off the corresponding adjusted flight distance. Keep in mind that this flight distance is a distance for a ship to follow where the flight grade does not exceed 29 percent. If the straight line grade from your unit to the landing exceeds 29 percent, the ship cannot safely fly a

straight line path; therefore, your straight line map distance must be increased. This effect is exaggerated on very short flight distances.

Gate 2

You now have a recommended flight distance adjusted for average sale costs and product value and can determine whether the resulting distance allows enough flexibility to proceed to gate 2.

Assume that the user has a better understanding of stand conditions in the analysis area. The objective is to determine whether the alternative should be fully analyzed or dismissed.

Step 1: Determine average delivered product value (dollars per unit).

Step 2: Estimate advertised rate plus brush disposal, road maintenance, road construction, and any additional required deposits (dollars per unit).

Step 3: Estimate haul cost from center of proposed project to nearest identified product manufacturing site.

Step 4: Determine available stump-to-truck cost (step 1 – [step 2 + step 3]). Compare this value to the value determined in step 8 below.

Step 5: Decide what type of helicopter available in your area meets your needs (Bell 204 or BV 107).

Step 6: Choose the silvicultural prescription that best describes the proposed treatment (regeneration, salvage/improvement, or intermediate/thinning).

Step 7: Decide what percentage of the target payload weight that you think will be achieved on average. Suggested range of load factor values in gate 1 can again be used if better field data is not available.

Step 8: Select the appropriate graph from figures 1 through 6. Locate your proposed flight distance on the x-axis, move vertically to the intersect point for the chosen load factor, move horizontally left to the y-axis, and read off the corresponding stump-to-truck cost (dollars per Mbf), keeping in mind the effect of flight path grade on adjusted flight path distance (see step 8 above in the subsection on gate 1).

You have now developed a stump-to-truck cost that can be compared to the available stump-to-truck cost calculated in step 4. Cost calculated in step 4 will be greater than, equal to, or less than cost calculated in step 8. For each eventuality, implications are as follows:

- *Step 4 is greater than step 8.* This suggests that product value will be adequate to cover all associated sale costs, including felling, yarding, and loading. The project would be considered economically feasible, and planning could proceed with full development of this alternative.

- *Step 4 is equal to step 8.* This suggests that this course filter is not adequate to determine whether the proposal is economically feasible. Options would be (1) to continue full development of the alternative, always looking for ways to improve one of the variables by increasing product value or decreasing costs; (2) to develop this alternative, but hold the project while monitoring market values for an increase in product value; and (3) to consult with a harvest system specialist for changes in input variables or design that would increase the sale potential.

- *Step 4 is less than step 8.* This suggests that product value will not be adequate to cover all associated sale costs. The project would not be considered economically feasible, and planning should not proceed with full development of this alternative as proposed. One of the options outlined above under "step 4 is equal to step 8" could be considered, or the alternative could be dismissed in chapter II of your NEPA document.

This study reflects standard operating conditions and helicopter logging safety practices, and recognizes the following limitations to helicopter capabilities:

Limitations

- *Load factors* less than 50Z generate unit costs that exceed a reasonable range for consideration. This occurs so infrequently that the cost generated for these conditions is based upon a very small sample size and should be suspect. There are no helicopter operations at these payloads unless product value is extremely high.

- *Flight distances* for the Bell 204 were limited to 20,000 feet and for the BV 107 to 25,000 feet. Beyond these distances, nearly all economic viability is exceeded.

- *Canopy closure* over the logs greater than 75 percent and canopy that contains limbs and tops large enough to pose an overhead hazard should be considered operationally unsafe.

- *Availability of helicopters* reflects a global market. Use of the method described in this article identifies sale economic viability, but does not directly address helicopter availability.

If you think you might have a proposal that exceeds any of these limitations, contact your regional logging engineer (406–329–3283 in Region 1).

Conclusions

Implementation of this course filter method can result in the identification of infeasible alternatives early in the timber sale planning process. Timber sale planning efficiency will be improved by reducing time spent on infeasible alternatives. This will reduce the number of advertised sales that receive no bids.

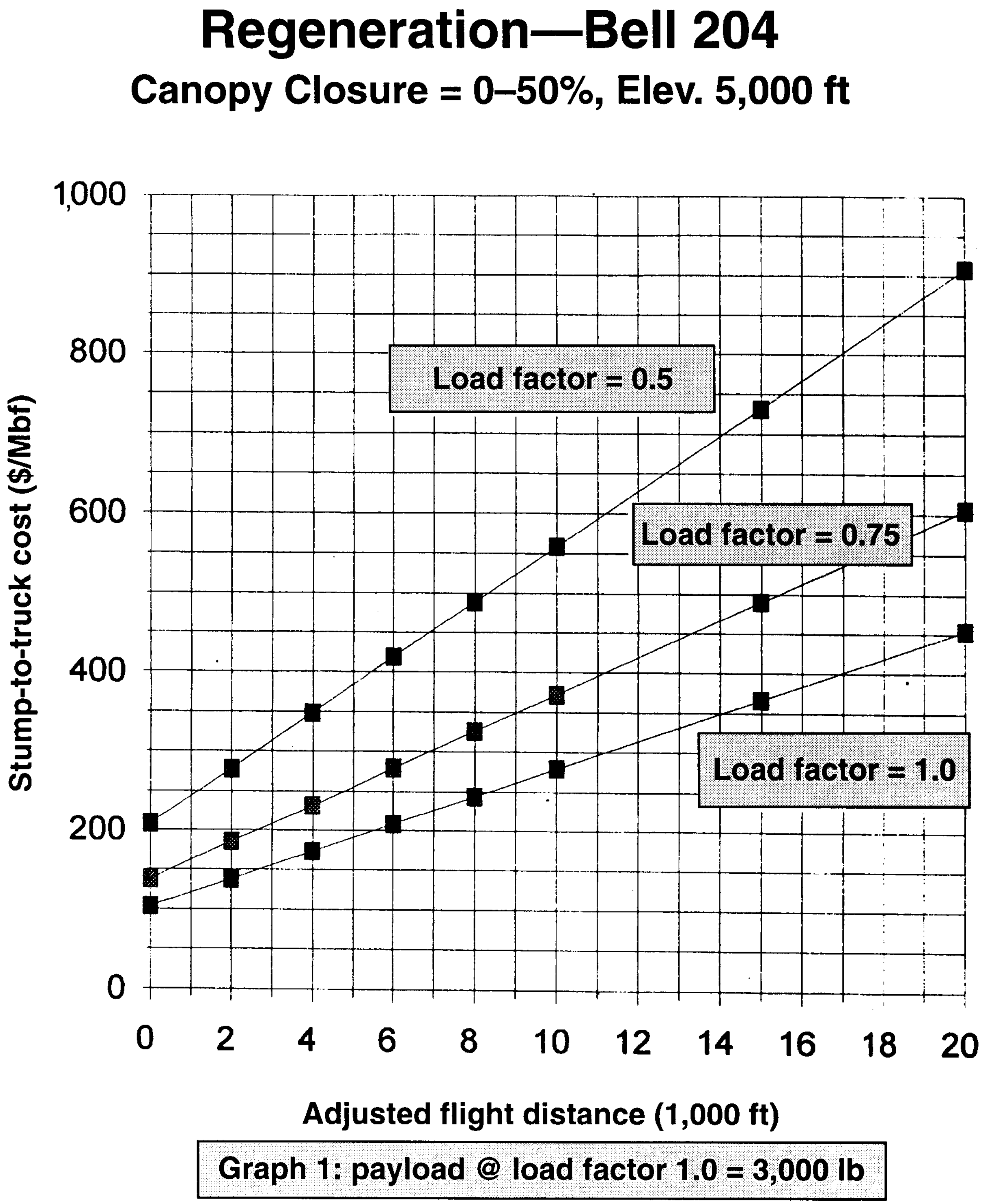

Figure 1.—Graph 1. Silvicultural prescription is regeneration. Helicopter type is Bell 204.

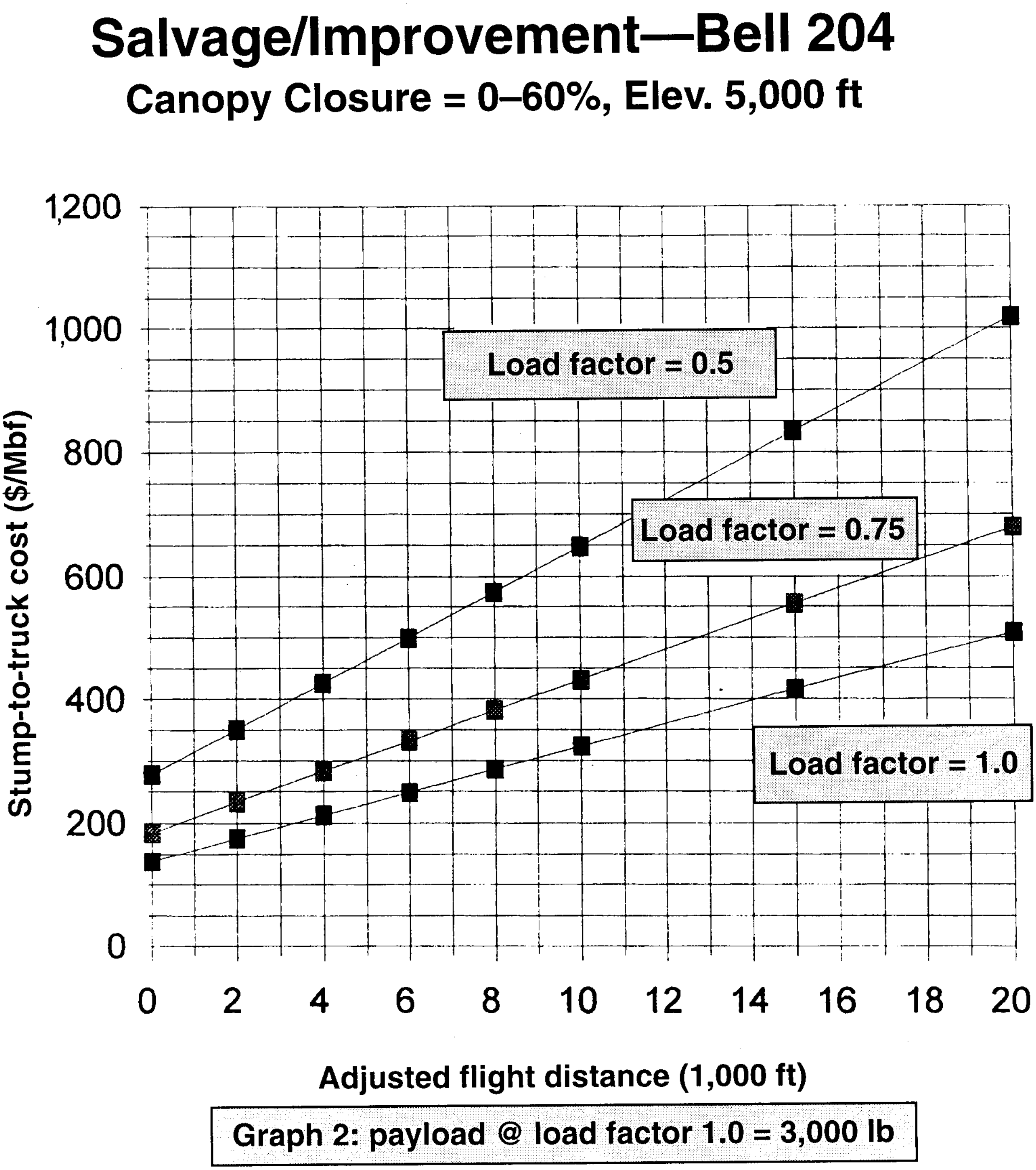

Figure 2.—Graph 2. Silvicultural prescription is salvage/improvement. Helicopter type is Bell 204.

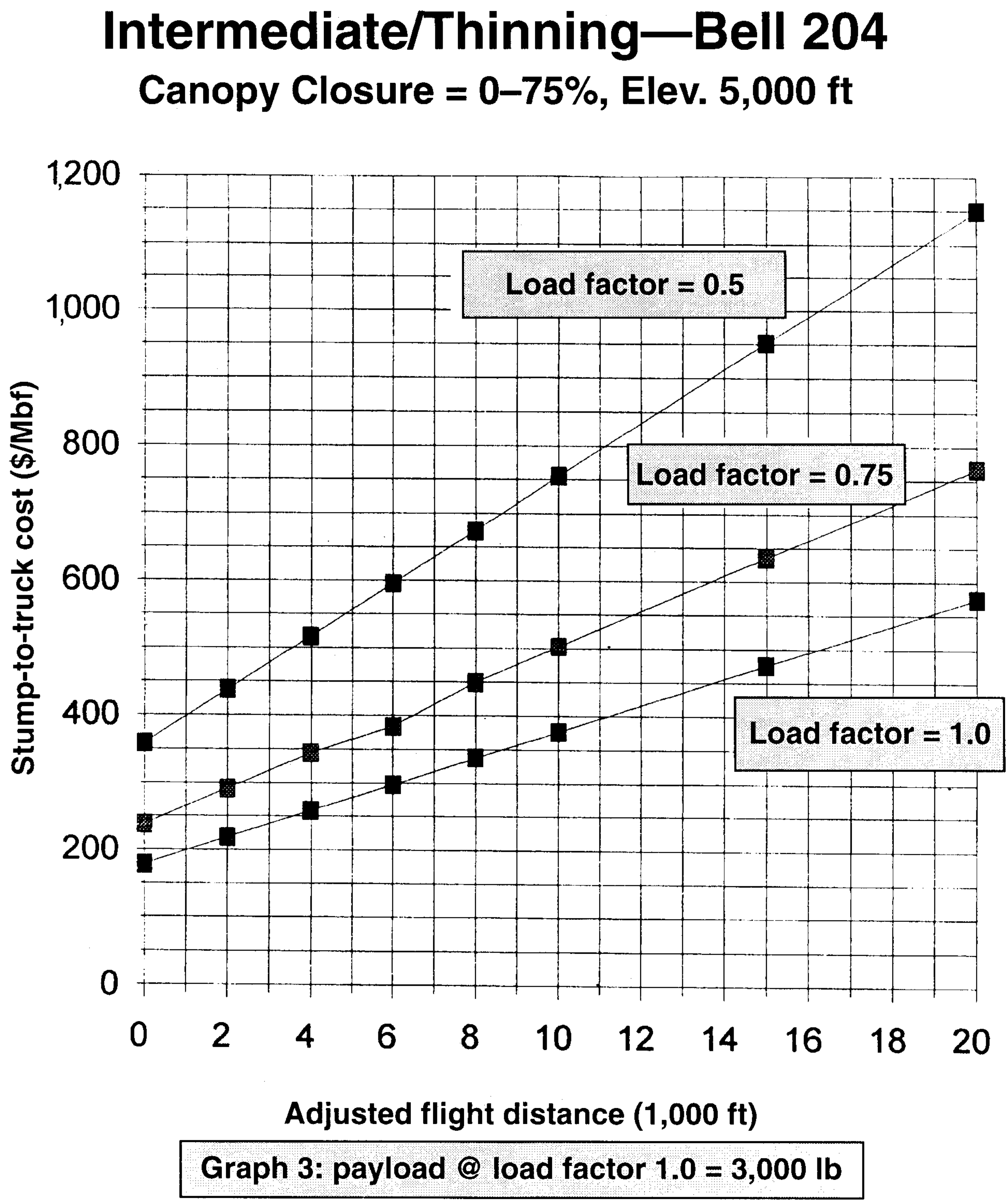

Figure 3.—Graph 3. Silvicultural prescription is intermediate/thinning. Helicopter type is Bell 204.

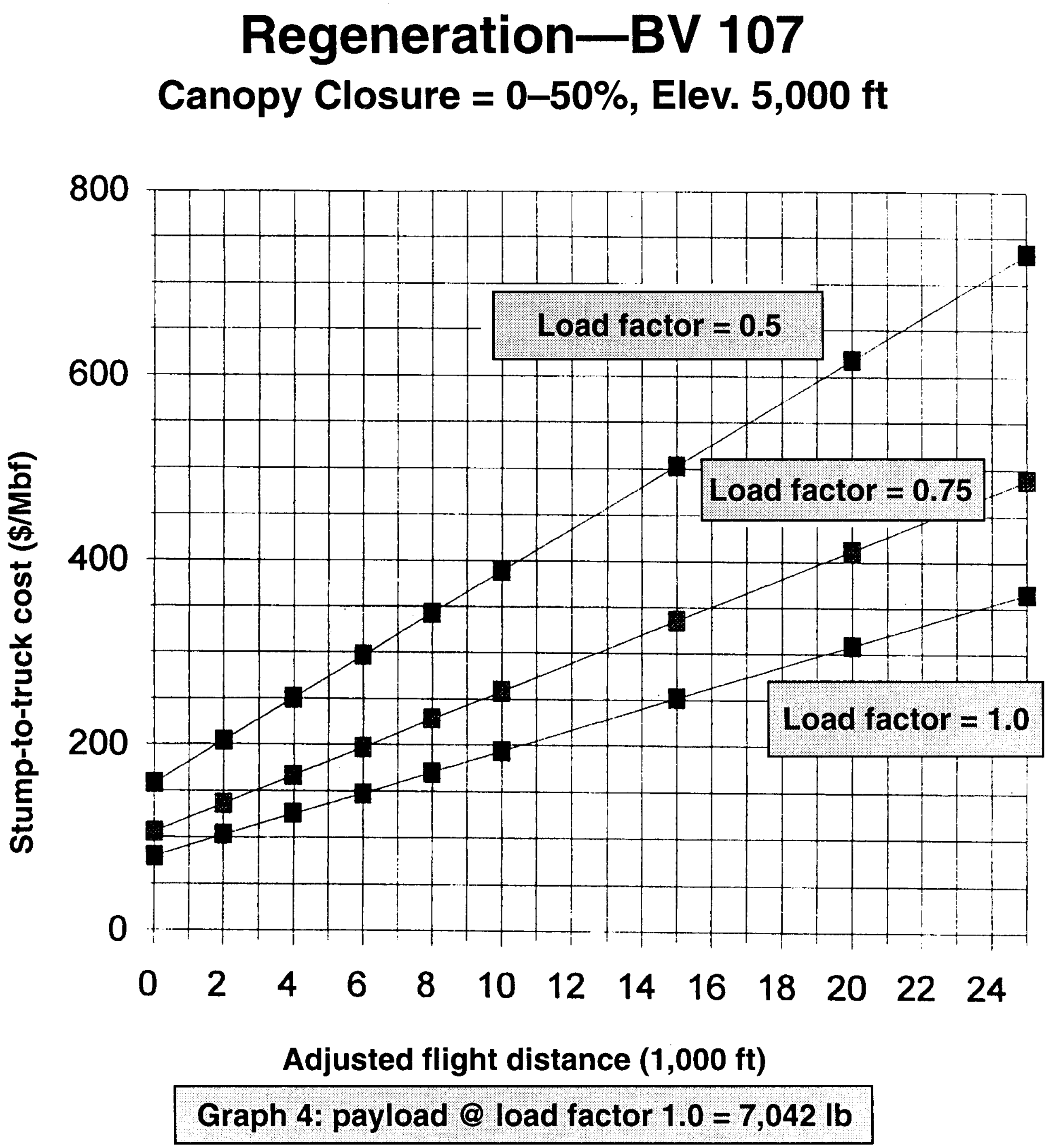

Figure 4.—Graph 4. Silvicultural prescription is regeneration. Helicopter type is BV 107.

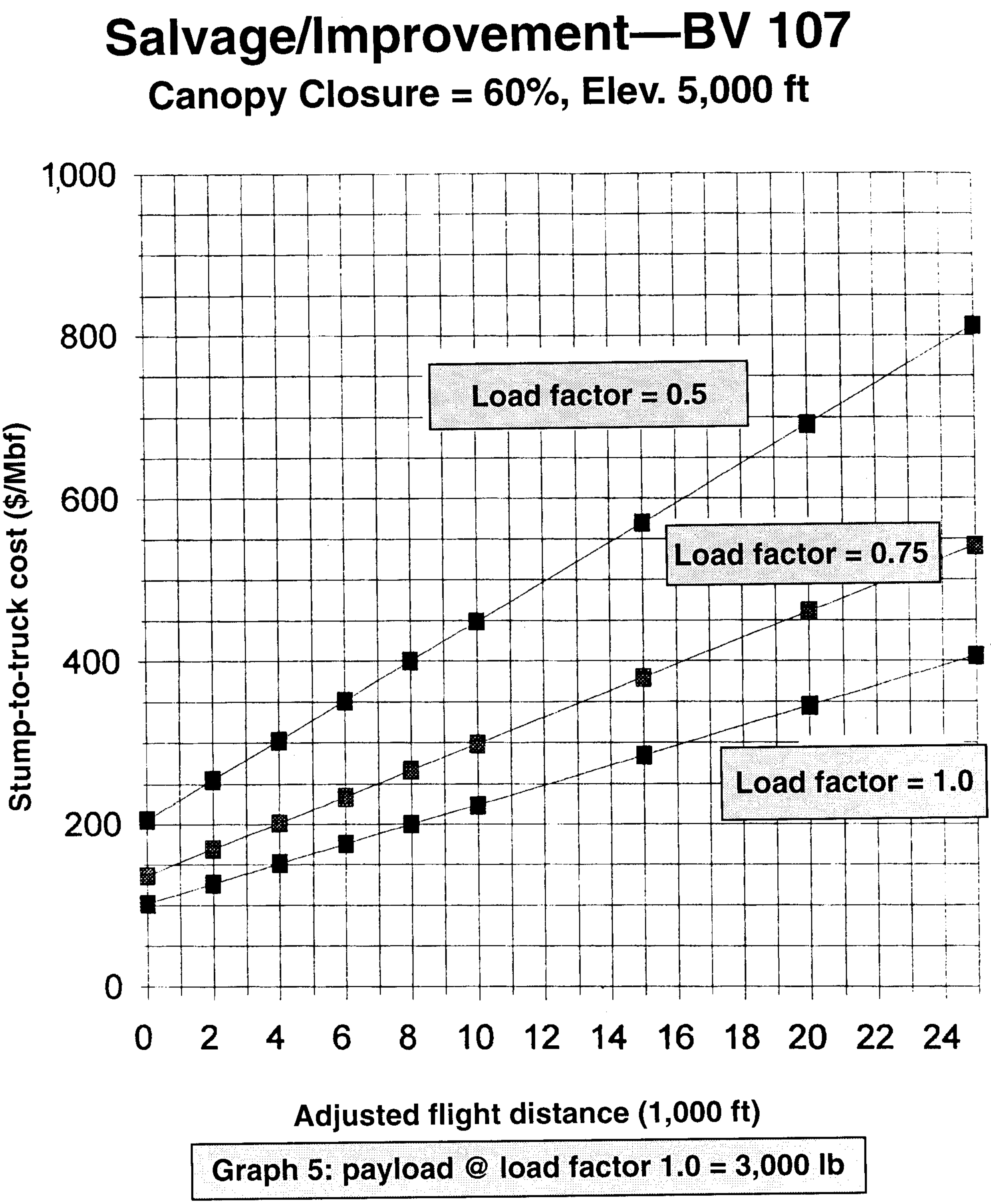

Figure 5.—Graph 5. Silvicultural prescription is salvage/improvement. Helicopter type is BV 107.

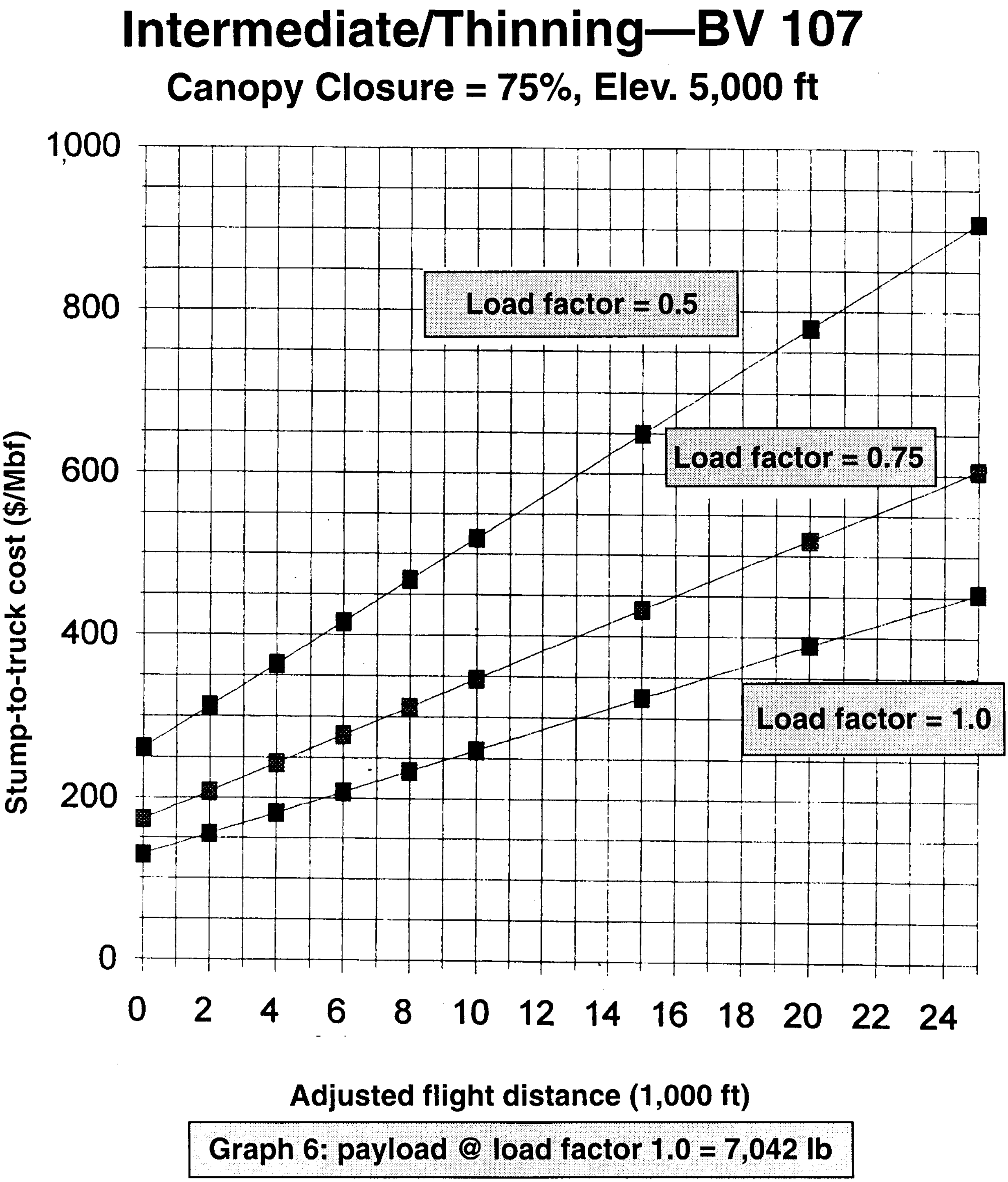

Figure 6.—Graph 6. Silvicultural treatment is intermediate/thinning. Helicopter type is BV 107.

How To Submit Proposals to the Technology and Development Centers' Engineering Technology Program

Keith Simila
Technology and Development Branch Chief
Washington Office Engineering

Do you have a need for technology transfer, product evaluation, or development of new on-the-ground applications in engineering? Many people do not realize that the engineering projects at the Missoula and San Dimas Technology and Development Centers originate from project proposals received from the field. The following information will assist you in having your project considered for the programs of work at the Centers.

What Types of Projects are Appropriate?

Project proposals can fall anywhere within the realm of engineering technology related to the development, operations, or maintenance of transportation systems, facilities, dams and structures, water and sanitation, hazardous materials, global positioning systems, or other related engineering disciplines. Both Centers have depth of expertise in many disciplines, and projects may be assigned to either, depending on skills needed and the need to balance programs between the two Centers. The Centers also rely heavily on experts from throughout the Forest Service, from other agencies, and from the private sector to complete specific projects.

What types of projects are appropriate? The Centers handle many resource development projects, but this article addresses only those related to engineering technology. Generally, the role of the engineering technology and development program is to provide technical support and expertise to field operations. The Centers:

- Develop new equipment or applications of technology to help you do your job better, more safely, or more efficiently.

- Conduct market searches of available tools, supplies, and equipment.

- Provide technology transfer through publications, videos, and personal contact.

All of these are appropriate types of projects within the technology and development program. Projects currently underway include development of time domain reflectivity technology to measure oil moisture in roads during low-strength periods, such as spring breakup; development of a mobile rock crusher that effectively processes aggregate from inplace roadbed material; development of a mixed-oxidant water disinfection system to treat surfacewater sources at remote sites; and technology transfer of state-of-the-practice energy conservation measures applicable to Forest Service sites.

Often, the Centers can informally handle simple requests for information, product sources, or technology transfer through a phone call or Data General message. Any project that requires more than a few days of staff time or costs more than a few hundred dollars in materials or supplies requires a written project proposal and is subject to steering committee review and approval.

Projects are oriented toward internal Forest Service and cooperator use. The Centers do not generally produce publications or videos designed exclusively for general audiences or distribution; this is the responsibility of public affairs staffs. Also, the Centers will not take on long-term projects better suited to the research branch of the Forest Service, but will partner with ongoing research to assist application to field needs.

How Are Proposals Evaluated?

Both Centers are organizationally part of Washington Office (WO) Engineering. However, a national Engineering Technology Steering Committee (ETSC) sets the direction for the technology and development program. Current ETSC members include:

Gary Marple	Chairperson	WO Engineering
Richard Sowa	ETSC Coordinator	WO Engineering
Beryl Johnston	Regional Engineer	Region 1, Regional Office
Donna Sheehy	Engineering Staff	Region 1, Regional Office
Marci Rider	District Engineer	Region 2, San Juan National Forest, Pagosa Springs Ranger District
Lou Liebbrand	Forest Engineer	Region 3, Coronado National Forest
Dave Neeley	Engineering Staff	Region 4, Regional Office
Belinda Walker	Sanitary Engineer	Region 5, San Bernardino National Forest
John Sloan	Forest Engineer	Region 6, Umpqua National Forest
Loren Evans	Engineering Staff	Region 8, Regional Office
Les Russell	District Ranger	Region 9, Huron–Manistee National Forest, Baldwin/White Cloud Ranger District
Jim Stapleton	Assistant Regional Engineer	Region 10, Regional Office

In December or January of each year, the ETSC sends a letter requesting project proposals to the regions and stations. Each spring and fall, the ETSC and advisors from the technology and development program review all new project proposals received since the previous meeting. The ETSC considers whether implementation of the project would likely improve field operations, provide resource protection, save money, and demonstrate use of emerging technology.

Each proposal is further evaluated against the following criteria:

1. Does the proposal fall within the role of technology and development?

2. Does the proposal have national significance?

3. Will the proposal provide direct benefits to field units?

4. Is the proposal feasible within time and dollar constraints?

5. Does the proposal provide opportunities for future partnership? (Can engineering funds be leveraged with funds from other sources?)

After the evaluation process is completed, the ETSC prioritizes the projects.

Then What?

After a proposed project has been evaluated and placed in priority order, the ETSC takes one of the following actions:

- The ETSC proposes the project, along with an estimated level of expenditure, to the Centers for their programs of work.

- The ETSC adds the proposal to the list of projects to be considered in the future.

- The ETSC determines that the proposal is better addressed by another staff group or by Forest Service Research, and forwards it to the appropriate WO sponsor.

- The ETSC determines that the proposed project is a low priority or inappropriate, and removes it from further consideration.

Anyone who submits a formal proposal will be notified after the meeting of the action taken.

Due to budget and staffing constraints, only high-priority projects are taken on each year. Funding for most engineering technology projects is budgeted from the WO or, in some cases, from other agencies, such as the Federal Highway Administration. If a project proposal is applicable only to a single region, station, or forest, the Centers may negotiate alternative funding with the unit that wants the project completed.

How To Submit Proposals

Sending in proposals is easy! Use the project proposal format at the end of this article to compose your electronic mail response. Proposals are usually no longer than two pages. Feel free to add any additional information that you think will help the steering committee to understand your proposal and to assess the time and funding needed to complete it.

Send your proposal (preferably electronically, but by mail is fine, especially if you need to add diagrams or figures) to one of the following:

Richard Sowa (R.SOWA:W01A)
USDA Forest Service
P.O. Box 96090 Washington, DC 20090-6090
(202) 205-1437

Tony Jasumback (T.JASUMBACK:R01A)
Missoula Technology and Development Center
Fort Missoula, Building #1
Missoula, MT 59801
(406) 329-3922

Paul Greenfield (P.GREENFIELD:W07A)
San Dimas Technology and Development Center
444 East Bonita Avenue
San Dimas, CA 91773
FTS (700) 793-8258 or commercial (909) 599-1267

Richard, Tony, or Paul will present your project proposal at the spring or fall steering committee meeting. It often helps to contact one of them prior to sending your proposal to discuss the process or the particulars of your request.

WO technical specialists who sponsor projects related to engineering technology are also sources of contact for submitting projects. They are:

Richard Sowa	Transportation Development	(202) 205-1437
Jim Padgett	Geotechnical and Dams	(202) 205-1448
Nelson Hernandez	Bridges and Structures	(202) 205-1433
Dave Erwin	Road Operations and Maintenance	(202) 205-1424
Tom Chappell	Facilities	(202) 205-1432
Terry Harwood	Water and Sanitation	(202) 205-1435
Mike Harper	Fleet	(202) 205-1646
Karen Solari	Hazardous Materials	(202) 205-0898

Engineering Technology Development Proposal Form

Proposal Name:

Submitted by:
Location:

Proposal Subject:

Proposal Description:

Estimated Benefits:

Estimated Expenditures:

Year 1	Year 2	Year 3	Etc.	
____	____	____	____	____

Full Recontouring and Channel Crossing Restoration Techniques for Closure and Obliteration of Low-Volume Roads

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Introduction

Recent attention has focused on the closure and obliteration of low-volume roads in forested and mountainous watersheds. The purpose of this article is to provide information submitted to the San Dimas Technology and Development Center on full recontouring of road prisms and channel crossing restoration techniques developed for use on road closure and obliteration projects in the Forest Service. The authors generically describe these efforts, drawing on experience from Regions 1, 2, and 6. The techniques we describe are considered the highest attainable and the most costly level of mechanical obliteration and hydrologic restoration for low-volume roads.

Recently, efforts have been made to return unneeded roads to natural resource production. This involves decompaction, reestablishment of subsurface flow, debris and rock placements, treatments to gullies and to their connectivity to stream systems, vegetative plantings, seeding, mulching, and, in extreme cases, reestablishment of original contours and removal of drainage structures.

Recontouring and channel crossing restoration are treatments for improving aquatic resources and hydrologic conditions. It must be noted that a wide range of natural and mechanical treatments exist for closing and obliterating road prisms. Full recontouring as a mechanical treatment resides at the intensive end of this range. On many unneeded roads, mechanical treatments are required only on certain segments, and recontouring is not often the preferred alternative. Consider channel crossing restoration for all unneeded roads, however, because drainage structures ultimately fail through plugging, piping, scour, undermining, overtopping, or diversion, and the drainage structures should therefore be removed.

Road closure and obliteration projects result from interdisciplinary forest resource and transportation planning efforts. These projects represent one step in a process that includes identifying needs, planning the work, implementing the project, and monitoring completed work.

Full recontouring as a road obliteration treatment is appropriate for unneeded prisms with critical problems in terms of access, drainage, erosion, stability, or revegetation, or in areas with significant cumulative-effects problems. Embankment material is removed and replaced in areas where excavation occurred during road construction to approximate the original topography. Channel crossing restoration is appropriate at sites with the potential for drainage structure failure, embankment washout, or stream diversion. The channel is restored to a condition that is as nearly natural as practicable or to another desirable condition. Heavy equipment used includes crawler tractors, excavators with hydraulic thumbs, front-end loaders, backhoes, dump trucks, and climbing backhoes, all appropriately sized to the job.

Many Forest Service units perform mechanical obliteration work under equipment rental agreements. This helps them gain experience and expedite smaller projects while allowing them to experiment with alternative techniques and equipment. Other benefits include ease in modifying the work plan. However, constant inspection is required, and success is largely determined by the skill and experience of contract inspectors as well as equipment operators. Equipment rental for large projects may prove uneconomical and lead to safety concerns and conflicts between operators. After experience is gained and techniques are defined for an area, solicitation of work through public works contracts allows for more effective and economical project implementation.

A Low-Volume Road Recontouring Technique

The recontouring technique described here involves two passes with an 18,000-kilogram-class (40,000-lb-class) excavator and was developed for 4.3-meter-wide (14-ft-wide) side-cast roads on steep sideslopes. The two-pass technique is considered the worst-case scenario; road segments on moderate sideslopes can be recontoured in one pass. Road prisms with high cutslopes or long slopes require execution of the two-pass technique. Landings and wider roads on steep slopes may require different equipment and techniques, because the excavator may not be economical if material must be handled multiple times.

Realize that the order of the first three steps could require adjustment; the work may be completed in stages; and modifications to the technique could be necessary to meet other needs or in other geographic areas.

Step 1

Materials required in postobliteration treatments are stockpiled at points of opportunity adjacent to the road prism. Materials include seedlings or plants, seed, mulch, fertilizer, and materials required for drainage restoration or monitoring. Large woody debris and rock to be spread within or adjacent to the corridor or in reshaped drainages are also collected and strategically placed.

Step 2

Required preobliteration removal of road appurtenances and treatments to adjacent areas are completed. This includes any work requiring access, such as removal of structures or obstructions, salvage of surfacing, landform modification or stabilization, treatments to skid trails and spur roads, channel improvement and canyon bottom treatments (a climbing backhoe may expedite this work), and silvicultural or fire treatments.

Step 3

Fill material deemed as excess to project needs may be excavated, hauled, and wasted offsite. Large embankments requiring tractors, front-end loaders, and end dumps for economical reduction are worked from sites furthest in prior to the recontouring operation. An excavator later shapes these sites.

Step 4

The travelway width, including turnouts and landings, is ripped with a crawler tractor, if this is necessary to facilitate excavation or revegetation, increase hydraulic conductivity, or break up the road surface "slip plane" and provide for interlock with the material placed upon it.

Step 5

Subsurface flow reestablishment systems are installed, if necessary.

Step 6

The excavator makes two passes in the recontouring operation. Starting at the beginning of the road segment to be recontoured, a 0.3- to 1.0-meter-high (1- to 3-ft-high) operating "platform" (figure 1) is built that allows the machine to reach the top-of-cut and provides a bench to support material replaced on the cutslope. Platform width must provide operating stability, yet should avoid encroaching on the fill. A higher top-of-cut dictates a higher platform; a platform may not be needed on gentle slopes or when the machine can easily reach the toe-of-fill and replace material at the top-of-cut. The material for this platform comes from the side-cast embankment as far down the fillslope as the machine can reach while operating from the platform and from "pioneer road" excavation, as described below in step 7. Efforts are made to provide a smooth transition from the top-of-cut to the replaced material.

Step 7

The pioneer road (figure 2) is excavated to provide access for the second pass, at a level low enough to allow the machine to easily reach the toe-of-fill. The excavator, operating on the platform, continues to pull reachable fill, placing it from the top-of-cut down to the platform.

Step 8

Materials encountered during the operation suitable for specific use in the project are salvaged and stockpiled.

Figure 1.—Excavator operating on platform.

Figure 2.—Pioneer road excavation.

Step 9

On the second pass (in the reverse direction), the excavator operates from the pioneer road to reach the toe-of-fill, removing all remaining embankment material and placing it where needed. Channel crossings are restored, as discussed below in the channel crossing restoration section.

Step 10

As the excavator works out, it obliterates the pioneer road, effectively completing the recontouring operation. Slopes are dressed; high and low points are smoothed; and the surface is left in a roughened condition to increase moisture-holding capabilities and to facilitate revegetation. Final placement of large woody debris and rocks is made on the recontoured slopes (figure 3). The excavator may also be used to transplant small trees and shrubs from the surrounding area to the recontoured corridor, a technique that has proven successful.

Figure 3.—Recontoured road prism.

Step 11

Work crews perform revegetation activities.

A Channel Crossing Restoration Technique

The basic channel crossing restoration technique for low-volume roads, shown step by step in figures 5 through 13, makes use of an 18,000-kilogram-class (40,000-lb-class) excavator (figure 4) and is applicable to fills ranging from 4.5 to 9 meters (15 to 30 ft) deep. Use of crawler tractors to reduce the fill by drifting material each way or use of front-end loaders and dump trucks may prove more economical for steps 2 through 5 (figures 6 through 10), although the excavator is best for special removal and placement of material, removal of pipe, and shaping of the site.

Figure 4.—Excavator removing a channel crossing embankment.

Step 1

Three or four operating levels (figure 5) and six or seven excavation points (figures 6 through 9 and 11 through 13) are required. The pipe is not always located in the channel bottom, as shown in figure 5; the pipe outlet may be "perched" on fill material, or the pipe may have been installed at a skew to the drainage path. The skew simplifies bedding and backfill of the pipe by removing it from the stream, which is later diverted into the pipe. Channel restoration targets should account for pipe installation techniques, if required.

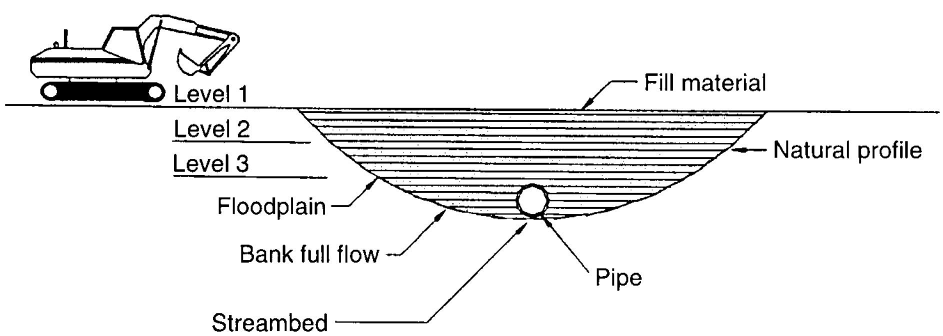

Figure 5.—Channel crossing restoration technique, step 1.

Step 2

Excavation point 1 (figure 6) is on the approach to the fill and at the road level; the next lower level is excavated from here and may not be in the actual fill. This is necessary to accommodate the large amount of fill to be removed, and may result in additional disturbance to soils and the site.

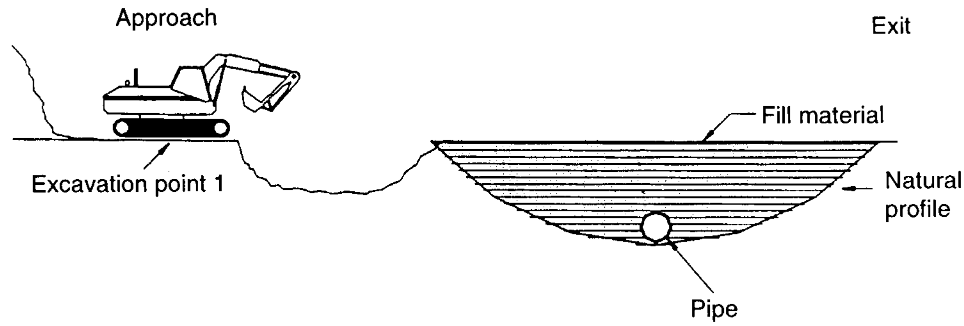

Figure 6.—Channel crossing restoration technique, step 2.

Step 3

The excavator begins mass removal of fill from excavation point 2 (figure 7), in the process digging down to the next lower level, which should permit reaching maximum required depth.

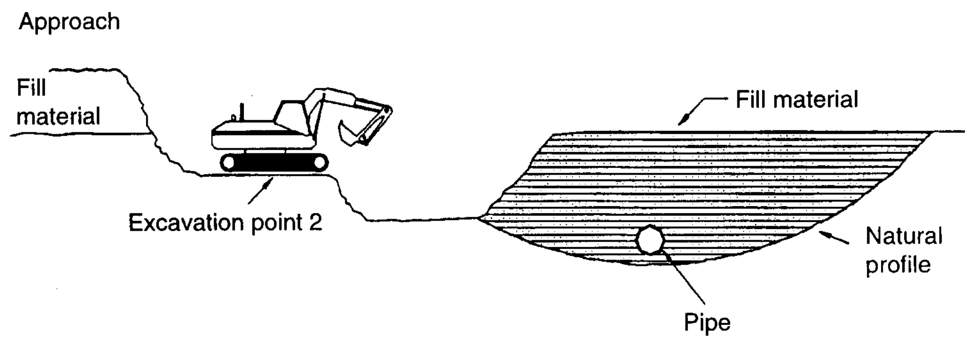

Figure 7.—Channel crossing restoration technique, step 3.

Step 4

From excavation point 3 (figure 8), the excavator removes fill both upstream and downstream of the road centerline until native soil—which may be difficult to identify—is encountered. Enough material must be left to provide a stable operating platform.

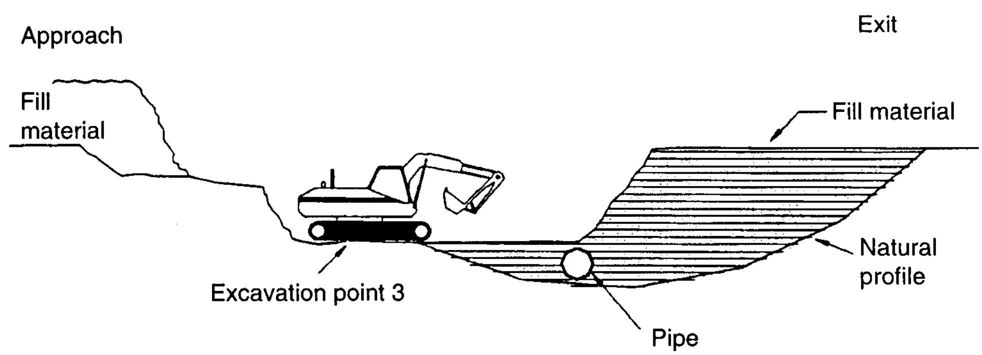

Figure 8—Channel crossing restoration technique, step 4.

Step 5

Excavation point 4 (figure 9) is directly over the low point of the channel and at the same level as point 3, from which the machine should be able to reach maximum depths required to remove all fill (figure 10).

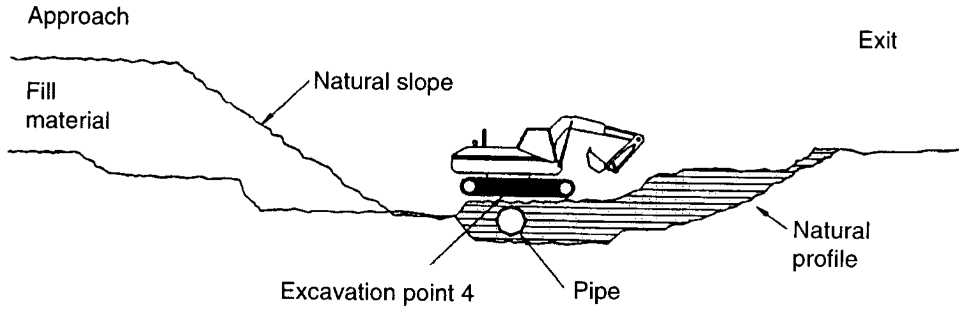

Figure 9.—Channel crossing restoration technique, step 5A.

Fills deeper than 9 meters (30 feet) may require the excavator to dig down to excavation points 3, 4, and 5 towards the uphill side of centerline first; separate excavation points are needed on the lower side due to the longer stretch of canyon length occupied by fill. Additional equipment may expedite removal of material, or the excavator may require several steps —handling material several times—to clear the channel of material. Maximize use of the approach side for material storage.

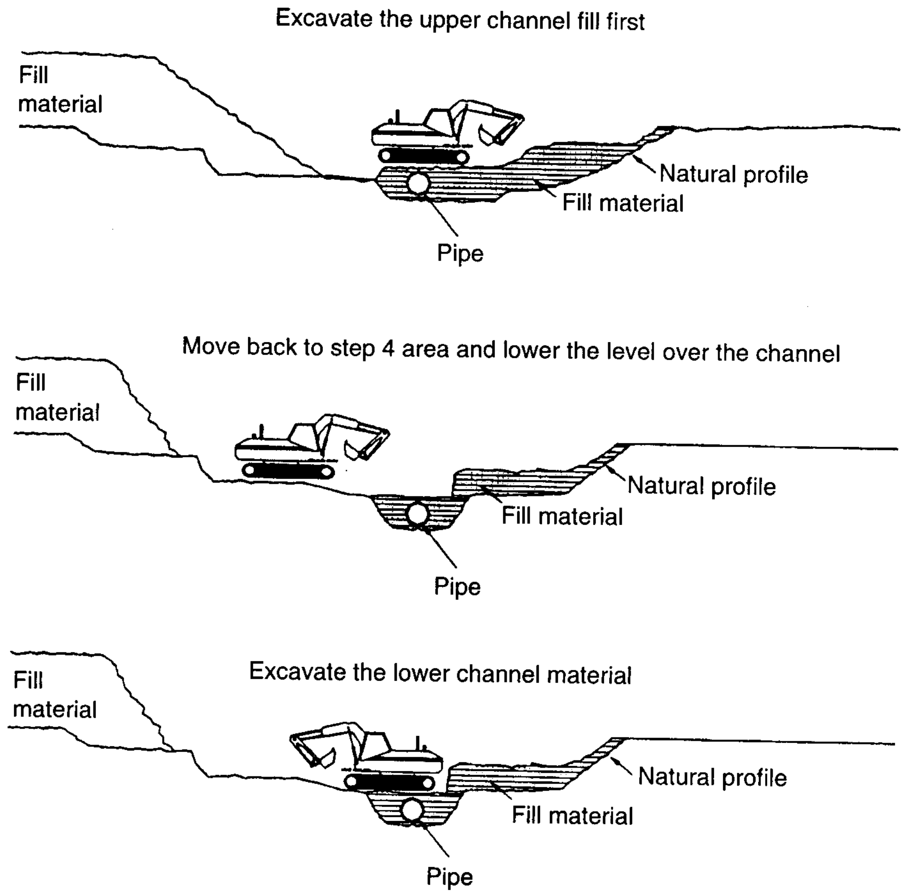

Figure 10.—Channel crossing restoration technique, step 5B.

Step 6

Excavation point 5 (figure 11) is on the ascending level. Remaining fill around the culvert is removed prior to removal of the pipe itself, after which disposal of the pipe may take place.

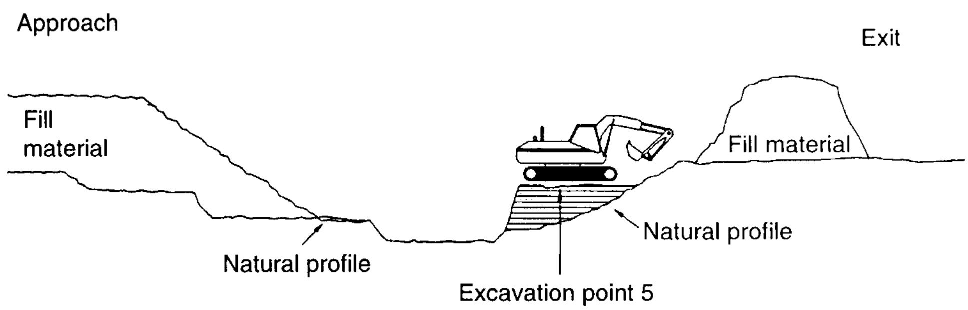

Figure 11.—Channel crossing restoration technique, step 6.

Step 7

Excavation point 6 (figure 12) is again at the road surface level, from which all remaining fill is removed from the channel area. At this point, the profile and cross section of the entire channel area are restored and shaped. Rock armoring and woody debris may be placed at this time (figures 13 and 14).

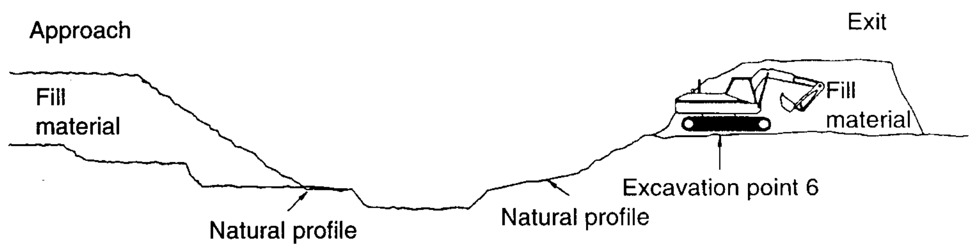

Figure 12.—Channel crossing restoration technique, step 7.

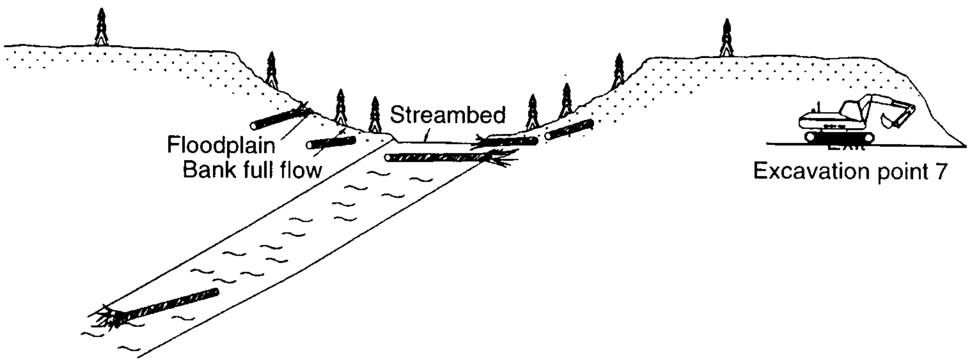

Figure 13.—Channel crossing restoration techniques, completed.

Excavation point 7 is occupied by the excavator to finish placement of materials and dress slopes on the exit side of the channel.

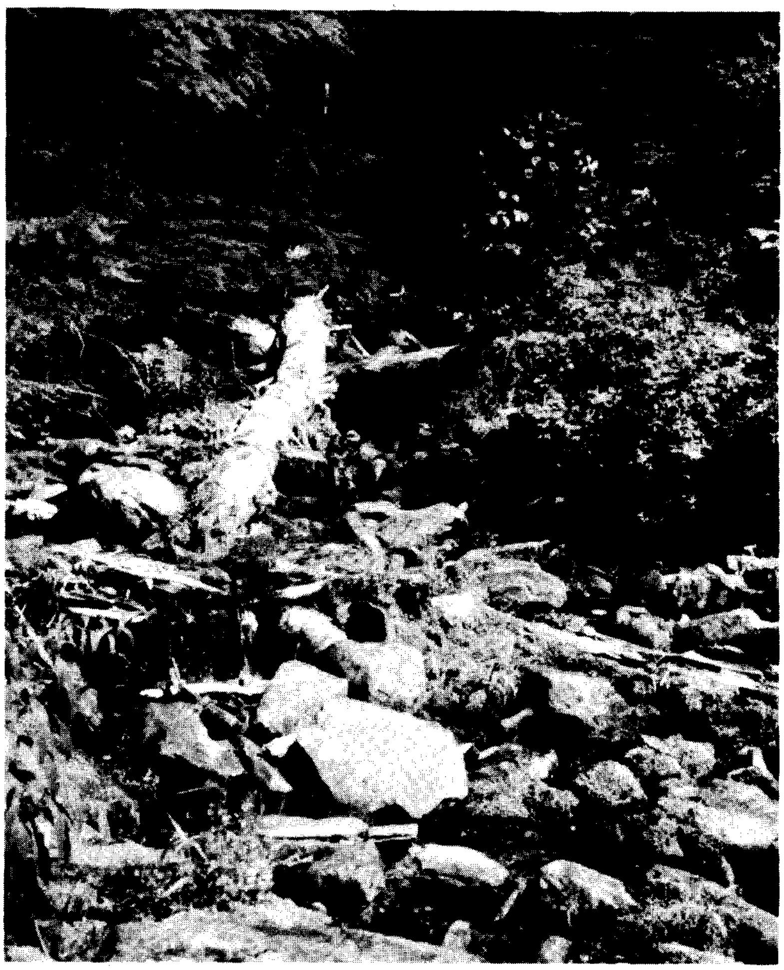

Figure 14.—Restored channel.

Some pointers on channel restoration are:

- This technique results in placement of most excavated material on the approach side of the channel. Efficiency is optimized by maximizing this quantity. Plan final deposition of material carefully, taking into account any need to recontour adjacent road sections and the mass diagram for the overall project.
- Maintain natural bank full flow capacity as dictated by channel characteristics above and below the site.
- To prevent clogging, blockages, and sedimentation, remove material outside the channel that is susceptible to movement into the channel.
- Minimizing channel scour often depends on reconstructing original channel structural elements. Appropriately place large woody debris and boulders.
- In live streams, remove all fill around pipes prior to bypass and pipe removal. Use sediment traps and silt fences to minimize sedimentation during and after excavation and to minimize the total volume of contaminated water.
- Perform careful channel restoration inspection, which is critical to environmental sensitivity due to proximity to streams and flow routing potential.
- Perform construction staking of excavation and embankment to facilitate location of excavation point 1 and placement of excavated material.
- Coordinate channel restoration efforts with other aspects of closure and obliteration work.
- Maintain safe and stable working platforms and conditions for all equipment and personnel.

Monitoring

All road-related effects on aquatic resources accumulate downstream; only those currently in progress or with future potential can be influenced. Effectiveness monitoring of completed closure and obliteration work can be performed only on road segments that had negative effects in progress. These may represent a fairly small subset of all negative effects that have already occurred or will occur. Much road closure and obliteration work represents risk reduction and is not easily monitored.

Load Rating of Single-Span Steel Girders for an HS20 Vehicle Using Mathcad® 5+

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Introduction

The National Bridge Inspection Standards require that bridges be inspected biannually and that load rating be conducted when conditions warrant. There are more than 575,000 bridges in existence today; as these structures age, load rating should be conducted when a significant change in condition occurs. Load ratings are time-consuming and costly. With ever-decreasing maintenance budgets, an economical and versatile load-rating worksheet would benefit many local, State, and Federal agencies. This process can now be accomplished quickly and accurately using computer spreadsheets or programs. This article develops an economical way of load rating a single-span, one-lane bridge for a standard American Association of State Highway Transportation Officials (AASHTO) HS20 vehicle.

The method developed uses Mathcad 5+ to calculate load ratings. Mathcad 5+ is a powerful mathematical tool that lets equations be written in real math notation and can be made into a worksheet. This article discusses steel-beam bridge load rating. Load ratings require calculations of maximum moments and shears due to standard vehicle loads. Two functions are also developed for calculating moments and shears using a Dynamic Linked Library (DLL) for Mathcad 5+. The single-span, one-lane bridge type was used because it is a common structure on the national forests and in many local municipalities.

Load Rating

The load-rating procedure used in this paper follows the method detailed in AASHTO's "Manual for Condition Evaluation of Bridges," 1994 edition, and the standard design specifications from AASHTO's "Standard Specifications for Highway Bridges," 15th edition. Load rating and structure inspection should meet the requirements for frequency of inspections, type of inspections, and qualifications of inspection personnel set by the National Bridge Inspection Standards.

Structures should be load rated for inventory and operating levels. Inventory rating is the stress level at which a live load can safely use the structure for an indefinite period or with indefinite repetitions. Operating rating is the stress level at the maximum permissible live load that the bridge shall bear. Allowing unlimited vehicular use at this stress level may shorten the life of the bridge. The vehicles that use the bridge at operating stress level require permits from the governing agency.

Mathcad 5+ and DLL's

Mathcad 5+ is computer software that allows formulas, numbers, graphics, and text to be placed onto a worksheet. They are integrated on the worksheet to be easy to follow and professional in appearance. Equations are shown in real math notation, and the changing of variables updates answers instantly. Modifying equations is simple, and results are obtained on the spot.

With Mathcad 5+ supporting DLL's, customized functions can now be developed to simplify Mathcad 5+ worksheets. These functions will be included as a built-in function of Mathcad 5+. One DLL developed for the load-rating worksheets contained two functions: Maximum Moment Due to Standard Moving Loads (mvldStdMaxM(span, type)) and Maximum Shear Due to Standard Moving Loads (mvldStdMaxV(span, type)). The mvldStdMaxM(span, type) function calculates the maximum moment of a single-span beam due to standard moving vehicles. The mvldStdMaxV(span, type) function calculates the maximum shear of a single-span beam due to standard moving vehicles. The span is the clear span of the bridge, and the type is (1) an AASHTO HS20 truck, (2) a Forest Service U54 truck, (3) a Forest Service U80 truck, (4) a Forest Service U102 truck, or (5) an L90 vehicle.

The procedure for developing a DLL is relatively simple, requiring only Mathcad 5+ and a 32-bit C++ compiler. The steps are:

1. Writing the source code in C or C++.

2. Compiling the source code with a 32-bit compiler.

3. Linking the object files with the **mcaduser.lib** file to create a DLL.

4. Placing the DLL in the directory **C:\mcad\userefi.** Mvldstd.dll is the name of the DLL created.

Mathcad 5+ allows for error checking in the DLL and will return user-friendly error messages. The errors checked for in the DLL developed following the above four steps are: span must be positive; span must be a real number; and type must be 1, 2, 3, 4, or 5.

Rating Procedures

The rating procedure that this paper follows is outlined in section 6 of AASHTO's "Manual for Condition Evaluation of Bridges." This procedure only addresses ratings of interior beams. A sample worksheet developed for steel-bridge girder rating is shown in the appendix.

Nomenclature

The following nomenclature is constant for the worksheet:

A	Area	A_{bf}	Area of bottom flange
A_T	Total area of beam	A_{tf}	Area of top flange
A_v	Area for shear	A_w	Area of web
Bridge_Span	Span of bridge in feet, measured from the centerline of bearing to the centerline of bearing		
CG	Center of gravity	C_t	Distance from CG to top
C_b	Distance from CG to bottom		
F_{b_inv}	Allowable inventory bending stress		
F_{b_oper}	Allowable operating bending stress		
F_{v_inv}	Allowable inventory shear stress		
F_{v_oper}	Allowable operating shear stress		
Inv_Rating	Bridge member rating in tons for inventory stress level		
I_X	Moment of inertia		
M_{R_inv}	Moment capacity of the member for inventory stress level		
M_{R_oper}	Moment capacity of the member for operating stress level		
M_{DL}	Moment due to dead load	M_{LL}	Moment due to live load
Num_of_Beams	Number of steel beams		
Oper_Rating	Bridge member rating in tons for operating stress level		
RF	Rating factor for the live load carrying capacity with subscripts for combinations of moment, shear, inventory, and operating		
S_{beam}	Beam spacing	S_X	Section modulus
V_{R_inv}	Shear capacity of the member for inventory stress level		
V_{R_oper}	Shear capacity of the member for operating stress level		
V_{DL}	Shear due to dead load	V_{LL}	Shear due to live load
Wt_{Wood}	Weight of wood (50 lb/ft^3, except native log stringers (40 lb/ft^3))		
b_{tf}	Width of top flange	b_{bf}	Width of bottom flange
d	Depth of beam	d_w	Depth of web
t_{bf}	Thickness of bottom flange	t_{tf}	Thickness of top flange
t_{Plank}	Thickness of planks	t_w	Thickness of web

Allowable Stresses

The stresses are given in table 6.6.2.1-1, Inventory Rating Allowable Stresses (psi), and table 6.6.2.1-2, Operating Rating Allowable Stresses (psi), in the "Manual For Condition Evaluation of Bridges."

Dead Load

The dead load is the weight of the member and any other permanent weight that will be carried by the member. The unit weights for materials in this calculation will follow AASHTO 3.3, Dead Load. The dead load on this structure is due to steel beams, timber decking and a running surface. The weight of wood is 50 lb/ft^3 and the weight of steel is 490 lb/ft^3, per AASHTO Design Specifications.

Live Load

The live load is the weight of a moving vehicle that is traveling across the bridge. The typical vehicle used in these load-rating worksheets is a standard AASHTO HS20 vehicle, per the "Manual for Condition Evaluation of Bridges." Functions for calculating maximum moment and shear have been developed for Mathcad 5+. MvldStdMaxM(span,type) will calculate the maximum moment for any simple span length due to five vehical types. MvldStdMaxV(span,type) will calculate the maximum shear for any simple span length due to five vehicle types.

Distribution of Live Load

The distribution of live loads to individual stringers will be determined in accordance with AASHTO 3.23, Distribution of Loads. The column with the boxhead "Bridge Designed for One Traffic Lane" in table 3.23.1, Distribution of Wheel Loads in Longitudinal Beams, was used for calculation of live load distribution for Steel (Hamilton EZ®) Bridges.

Impact Factor

An impact factor must be included in the live load when required by the AASHTO Design Specifications. The impact factor is determined by the following AASHTO formula:

$$\textit{Impact Fraction} = \frac{50}{\textit{Bridge Span} + 125} \leq 0.3$$

For application requirements of impact factors, see AASHTO 3.8, Impact.

Rating Formula

The rating factor equation (6-la) for allowable stress design is:

$$\textit{Rating Factor} = \frac{\textit{Member Capacity} - \textit{Member Dead Load Effect}}{\textit{Member Live Load Effect} \times (1 + \textit{Impact Factor})}$$

where the load effect is the effect of the applied loads on the member. The bridge rating equation (6-lb) is:

$$\textit{Bridge Member Rating} = \textit{Rating Factor} \times \textit{Nominal Truck Weight}$$

where the bridge member rating and nominal weight are in tons. These worksheets rate interior beams for shear and bending. Other elements of these types of bridges, such as decks and substructure, also need to be rated.

Summary

The Mathcad 5+ worksheet has worked well for load rating this type of structure. Alterations may be made with ease for load rating other bridge types. For example, the bridge-rating worksheet (see appendix) was developed for a standard HS20 vehicle, but U54, U80, and U102 trucks and an L90 vehicle can be accommodated in the worksheet with minor effort. The maximum shear and moment functions have these standard vehicles built into them. In addition, only one-lane bridges were rated; however, the worksheet could be expanded to rate multilane bridges. Load rating bridges using Mathcad 5+ turned out to be a very economical and viable solution for these bridge types. With minor effort, it could be implemented for other types of bridges.

References

American Association of State Highway and Transportation Officials. Manual for condition evaluation of bridges. Washington, DC: American Association of State Highway and Transportation Officials; 1994. 136 p.

American Association of State Highway and Transportation Officials. Standard specifications for highway bridges. 15th ed. Washington, DC: American Association of State Highway and Transportation Officials; 1994. 686 p.

MathSoft, Inc. Mathcad® 5+ for Windows. 2d ed. Wellesley, MA: RPJ Associates, 1994.

Appendix

Steel-Bridge Girder Rating

The following program rates single-span, one-lane steel bridges (Hamilton EZ) using the procedure described in the "Manual for Condition Evaluation of Bridges" published by AASHTO, 444 North Capitol Street, NW, Suite 249, Washington, DC 20001. This worksheet considers only interior stringers.

General Information

Bridge_Span:= 38.75 in feet. Measure from center to center of bearing.

$t_w := .46 \cdot in$	$d_w := 25.75 \cdot in$	$Wt_{Steel} := 490 \cdot \frac{lb}{ft^3}$	Num_of_Beams:= 4
$t_{tf} := .64 \cdot in$	$b_{tf} := 9.96 \cdot in$	$Wt_{Wood} := 50 \cdot \frac{lb}{ft^3}$	$S_{Beam} := 4.5 \cdot ft$
$t_{bf} := .64 \cdot in$	$b_{bf} := 9.96 \cdot in$		$t_{Plank} := 8 \cdot in$
$d := d_w + t_{tf} + t_{bf}$	$d = 27.03 \cdot in$		$kips := 1000 \cdot lb$

Section Properties

$A_V := d \cdot t_w$ $\quad A_V = 12.43 \cdot in^2$

$A_T := t_w \cdot d_w + t_{bf} \cdot b_{bf} + t_{tf} \cdot b_{tf}$ $\quad A_T = 24.59 \cdot in^2$

$A_w := t_w \cdot d_w \qquad A_{tf} := t_{tf} \cdot b_{tf} \qquad A_{bf} := t_{bf} \cdot b_{bf}$

$$CG := \frac{\left[A_{tf} \cdot \frac{t_{tf}}{2} + A_{W} \cdot \left(t_{tf} + \frac{d_w}{2}\right)\right] + \left[A_{bf} \cdot \left(t_{tf} + d_w + \frac{t_{bf}}{2}\right)\right]}{\frac{lb}{ft} \quad A_T} \qquad CG = 13.51 \cdot in$$

$$I_x = \frac{b_{tf} t_{tf}^3}{12} + A_{tf} \cdot \left(CG - \frac{t_{tf}}{2}\right)^2 + \frac{t_w \cdot d_w^3}{12} + A_w \cdot \left[\left(\frac{d_w}{2} + t_{tf}\right) - CG\right]^2 + \frac{b_{bf} \cdot t_{bf}^3}{12} + A_{bf} \cdot \left(d - CG - \frac{t_{bf}}{2}\right)^2 \qquad I_x = 2874.6 \cdot in^4$$

$C_t := CG \qquad C_t = 13.51 \cdot in \qquad C_b := d - CG \qquad C_b = 13.51 \cdot in$

$S_{xt} := \frac{I_x}{C_t} \qquad S_{xt} = 212.7 \cdot in^3 \qquad S_{xb} := \frac{I_x}{C_b} \qquad S_{xb} = 212.7 \cdot in^3$

$S_x := if(S_{xt} > S_{xb}, S_{xb}, S_{xt})$ $\qquad S_x = 212.7 \cdot in^3$

Allowable Stresses

from Table 6.6.2.1-1 and table 6.6.2.1-2 of the "Manual for Condition Evaluation of Bridges."

$F_{b\_inv} := 27000 \cdot \frac{lb}{in^2} \qquad F_{v\_inv} := 17000 \cdot \frac{lb}{in^2}$

$F_{b\_oper} := 37500 \cdot \frac{lb}{in^2} \qquad F_{v\_oper} := 22500 \cdot \frac{lb}{in^2}$

Calculation of Dead Load Moments and Shears

$DL_{Deck} := S_{Beam} \cdot t_{Plank} \cdot Wt_{Wood}$ $\qquad DL_{Deck} := 150 \cdot \frac{lb}{ft}$

$DL_{Beam} := A_T \cdot Wt_{Steel}$ $\qquad DL_{Beam} := 83.69 \cdot \frac{lb}{ft}$

$DL_{Running\_Surface} := 20 \cdot \frac{lb}{ft}$ $\qquad DL_{Running\_Surface} := 20 \cdot \frac{lb}{ft}$

$DL_{Total} := DL_{Deck} + DL_{Beam} + DL_{Running\_Surface}$ $\qquad DL_{Total} := 253.69 \cdot \frac{lb}{ft}$

$M_{DL} := \frac{DL_{Total} \cdot (Bridge\_Span \cdot ft)^2}{8}$ $\qquad M_{DL} = 47.62 \cdot ft \cdot kips$

$V_{DL} := \frac{DL_{Total} \cdot (Bridge\_Span \cdot ft)}{2}$ $\qquad V_{DL} = 4.92 \cdot kips$

Calculation of Live Load Moments and Shears

This worksheet is set up for calculating HS20 live load moments and shears for simple span bridges. The worksheet can also be set up for four other standard vehicle Truck_Types: 1 - HS20, 2 - U54, 3 - U80, 4 - U102, and 5 - L90 (see distribution factors for live load below). The live load shear has been computed for a distance three times the beam depth or the quarter point, whichever is less. The shear at this point has been approximated by using a shear envelope approach.

Truck_Type:= 1

$M_{HS20} := \text{mvldStdMaxM(Bridge\_Span, Truck\_Type)} \cdot ft \cdot kips$ $\qquad M_{HS20} = 213.81 \cdot ft \cdot kips$

$V_{HS20} = \text{mvldStdMaxV(Bridge\_Span, Truck\_Type)} \cdot kips$ $\qquad V_{HS20} = 27.33 \cdot kips$

Impact Factor

(from AASHTO 3.8.2)

$$I_{test} := \frac{50}{\text{Bridge\_Span} + 125} \qquad I_{test} = 0.31$$

$$I := \text{if}(I_{test} < .3, I_{test}, .3) \qquad I = 0.3$$

Distribution of Live Load Moment and Shear

The following is the live load distribution factor for bridges designed for one traffic lane, from AASHTO, Table 3.23.1. Beam Spacing in feet.

Kind of Floor	Distribution Factor
Timber planks on Steel Stringers 4" thick	Beam Spacing/4.5
Timber planks on Steel Stringers 6" or more thick	Beam Spacing/5.25

Note: If beam spacing is greater than 5.5 feet. Assume flooring between stringers acts as a simple beam.

$$DF_{LL} := \frac{S_{Beam}}{5.25 \cdot ft} \qquad DF_{LL} = 0.86$$

$$M_{LL} := M_{HS20} \cdot (1 + I) \cdot DF_{LL} \qquad M_{LL} = 238.24 \cdot ft \cdot kips$$

$$V_{LL} := V_{HS20} \cdot (1 + I) \cdot DF_{LL} \qquad V_{LL} = 30.45 \cdot kips$$

Load Rating—Moment

$M_{R\_inv} := F_{b\_inv} \cdot S_x$ $\qquad M_{R\_inv} = 478.57 \cdot ft \cdot kips$

$M_{R\_oper} := F_{b\_oper} \cdot S_x$ $\qquad M_{R\_oper} = 664.68 \cdot ft \cdot kips$

$$RF_{M\_inv} := \frac{M_{R\_inv} - M_{DL}}{M_{LL}} \qquad RF_{M\_inv} = 1.81$$

$$RF_{M\_oper} := \frac{M_{R\_oper} - M_{DL}}{M_{LL}} \qquad RF_{M\_oper} = 2.59$$

HS20_Inv_Rating_M:= $RF_{M\_inv} \cdot 36 \cdot ton$ $\qquad$ HS20_Inv_Rating_M= $65.1 \cdot ton$

HS20_Oper_Rating_M:= $RF_{M\_oper} \cdot 36 \cdot ton$ $\qquad$ HS20_Inv_Rating_M= $93.2 \cdot ton$

Load Rating—Shear

$$V_{R\_inv} := \frac{2}{3} \cdot A_V \cdot F_{v\_inv} \qquad V_{R\_inv} = 140.92 \cdot kips$$

$$V_{R\_oper} := \frac{2}{3} \cdot A_V \cdot F_{v\_oper} \qquad V_{R\_oper} = 186.51 \cdot kips$$

$$RF_{V\_inv} := \frac{V_{R\_inv} - V_{DL}}{V_{LL}} \qquad RF_{V\_inv} = 4.47$$

$$RF_{V\_oper} := \frac{V_{R\_oper} - V_{DL}}{V_{LL}} \qquad RF_{V\_oper} = 5.96$$

HS20_Inv_Rating_V:= $RF_{V\_inv} \cdot 36 \cdot ton$ $\qquad$ HS20_Inv_Rating_V= $160.8 \cdot ton$

HS20_Oper_Rating_V:= $RF_{V\_oper} \cdot 36 \cdot ton$ $\qquad$ HS20_Oper_Rating_V= $214.7 \cdot ton$

Final Load Rating

This final step compares the capacity of the bridge in shear and bending. The result is the lesser of the two.

Inv_Rating:= if(HS20_Inv_Rating_V<HS20_Inv_Rating_M, HS20_Inv_Rating_V, HS20_Inv_Rating_M)

Oper_Rating:= if(HS20_Oper_Rating_V<HS20_Oper_Rating_M, HS20_Oper_Rating_V, HS20_Oper_Rating_M)

This bridge has an HS20 Inventory Load Capacity of $\qquad$ Inv_Rating = $65.1 \cdot ton$

This bridge has an HS20 Operating Load Capacity of $\qquad$ Oper_Rating = $93.2 \cdot ton$

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