

AD-A156 913

BREACHING OF OBSTACLES (AN ENGINEER ASSESSMENT
METHODOLOGY)(U) ARMY ENGINEER STUDIES CENTER FORT
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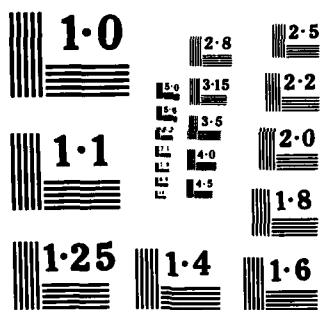
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BREACHING OF OBSTACLES

[AN ENGINEER ASSESSMENT METHODOLOGY]

AD-A156 913



Prepared by
Engineer Studies Center
US Army Corps of Engineers

June 1985

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM												
1. REPORT NUMBER	2. GOVT ACCESSION NO. <u>AD-A156 913</u>	3. RECIPIENT'S CATALOG NUMBER												
4. TITLE (and Subtitle) Breaching of Obstacles (An Engineer Assessment Methodology)		5. TYPE OF REPORT & PERIOD COVERED FINAL												
7. AUTHOR(s) Mr. Terry O. Atkinson MAJ Glenn F. Weien		6. PERFORMING ORG. REPORT NUMBER USAESC-R-85-5												
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Engineer Studies Center Casey Bldg. 2594 Fort Belvoir, VA 22060-5583		8. CONTRACT OR GRANT NUMBER(s)												
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Engineer Studies Center Casey Bldg. 2594 Fort Belvoir, VA 22060-5583		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS												
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE JUNE 1985												
		13. NUMBER OF PAGES 59												
		15. SECURITY CLASS. (of this report) UNCLASSIFIED												
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE NA												
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited														
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) NA														
18. SUPPLEMENTARY NOTES Portions presented to the Army Operations Research Symposium, 2 October 1984.														
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) <table border="0"> <tr> <td>Combat</td> <td>Bridge</td> <td>Berm</td> </tr> <tr> <td>Engineer</td> <td>Ford</td> <td>Model</td> </tr> <tr> <td>Obstacle</td> <td>Bypass</td> <td>Production Factor</td> </tr> <tr> <td>Mobility</td> <td>Tank Ditch</td> <td></td> </tr> </table>			Combat	Bridge	Berm	Engineer	Ford	Model	Obstacle	Bypass	Production Factor	Mobility	Tank Ditch	
Combat	Bridge	Berm												
Engineer	Ford	Model												
Obstacle	Bypass	Production Factor												
Mobility	Tank Ditch													
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes how the Engineer Studies Center (ESC) developed algorithms for estimating the combat engineer support required to overcome common obstacles to the forward movement of a military force. Although the algorithms were originally designed for use by the Combined Forces Command, Korea, they can be revised to consider terrain types not found on the Korean peninsula. The algorithms consider both assault and follow-on														

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20. ABSTRACT--

efforts for bridging, bridge bypasses, fords, and manmade obstacle systems, such as tank ditches, dragon's teeth, boulder fields, and concrete side drops.

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BREACHING OF OBSTACLES
(AN ENGINEER ASSESSMENT METHODOLOGY)

Prepared by
Engineer Studies Center
US Army Corps of Engineers

June 1984



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ACKNOWLEDGEMENTS

The Engineer Studies Center (ESC), US Army Corps of Engineers (USACE), conducted this analysis under the sponsorship of the Combines Forces Command, Korea. This report was derived from that analysis, and was first presented by Mr. Terry Atkinson at the 1984 Annual US Army Operations Research Symposium (AORS) at Fort Lee, Virginia.

This report was prepared under the overall direction of Mr. Lyle G. Suprise (Senior Project Manager) and Mr. Elton Underwood (Project Manager), and was written by Mr. Terry Atkinson and MAJ Glenn F. Weien.

This report was prepared for publication by Ms. Stacia L. Hall and Miss Donna L. Jones, under the supervision of Miss Anne E. Purcell. It was edited by Ms. Mary L. Scala.

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ANNEX--BASIC PROGRAM FOR ENGINEER MOBILITY ESTIMATES

A-1

BREACHING OF OBSTACLES
(AN ENGINEER ASSESSMENT METHODOLOGY)

1. Purpose. This report describes algorithms which can be used to calculate the combat engineer support required to overcome various common obstacles to the forward movement of a military force.

2. Background. Engineer doctrine contains a wealth of "how to" guidance for estimating the resources required to support countermobility missions, but little current information is available on how to estimate the support requirements for mobility missions. The Engineer Studies Center (ESC), at the request of the Combined Forces Command in the Republic of Korea, developed several algorithms designed specifically to estimate engineer mobility effort. These mobility algorithms are useful for calculating the military and paramilitary effort required to overcome various common obstacles on selected advance routes in Korea; as such, their calculations reflect the peculiarities of the terrain found on the Korean peninsula. This report details how ESC developed these mobility algorithms, so members of the engineer analytic community concerned with other geographic areas can revise the algorithms and apply them to a variety of terrain types.

3. Scope. ESC looked at three breaching forces, each equipped differently:

a. A force having only those items of equipment typically found in a civilian construction firm.

b. A force supplemented with equipment typically found in South Korean engineer units.

c. A force supplemented with equipment typically found in US engineer units.

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4. Assumptions. ESC made several assumptions about the removal of obstacles:

- a. Breach attempts take place during the day and in good weather.
- b. The breach must support a US mechanized force.
- c. Work is not hampered by enemy suppressive fires.
- d. Travel time to the obstacle sites is not part of the removal effort, and therefore not included in the effort calculations.
- e. The time needed to reconnoiter an obstacle site and to develop a breaching plan is not part of the removal effort, and therefore not included in the effort calculations.
- f. Obstacle systems are not reinforced by minefields or boobytraps.
- g. All manmade obstacles have been executed completely (for example, all bridge spans and intermediate support columns are destroyed).

5. Study Approach.

a. The analysis focuses on two levels of effort: an assault effort and a follow-on effort.

(1) The assault effort estimates the minimum engineer effort required to support the assaulting forces. This effort makes obstacle breaches just wide enough to pass attacking combat vehicles. The only roadwork done is the slope reduction necessary to make stream banks or berms passable.

(2) The follow-on effort is that effort needed to make the route passable for the vehicles in the battalion and brigade combat trains. Follow-on effort concentrates on providing one-way roads (where required) and bridges. These roads are less than Class C in quality and are expected to last only a few hours before requiring improvement. The bridges are the

minimum required to support the forward movement of armored vehicles and supplies.

b. Four categories of obstacles are examined:

(1) Bridges. The gap over which the bridge was built impedes traffic after the bridge is removed.

(2) Bypasses. A bypass can be built instead of constructing a new bridge at the location of the old bridge. The bypasses discussed in this report are located either at the bridge site or a reasonably short distance from the bridge site.

(3) Fords. Most fords used by civilian vehicles will have to be upgraded by the engineers before they can support military traffic.

(4) Manmade obstacles. Manmade obstacles such as tank ditches, dragon's teeth, boulder fields, and concrete side drops will require some effort to remove or overcome.

6. Bridge Engineer Estimates.

a. Overview. ESC's bridge evaluations are based mainly on bridge lengths and whether the gaps crossed are wet or dry. One requirement for this study was to calculate the engineer effort based on different equipment which was available to the forces moving along the routes. This requirement strongly influenced ESC's bridge assessments, since equipment differences are most pronounced in the area of military bridging, creating dramatic fluctuations in required construction times. To cover such equipment-related variables, ESC used a decision tree to evaluate which type of bridge equipment would be best suited to the different bridging obstacles along the study routes. However, ESC did not consider float bridging as a possible response to a bridge obstacle; float bridging is considered a response at a bypass

area. The logic for this decision is that at the site of a destroyed bridge, float bridging cannot be directly placed in the water--a nearby site with good access to the water must be found. This nearby site is typically a bypass area.

b. Assumptions, and Their Significance.

(1) ASSUMPTION: All bridges have had all spans dropped. SIGNIFICANCE: The attacking forces will have to bridge the full length of the gap. If all spans are not down, then the estimated time for bridging the gap can be reduced.

(2) ASSUMPTION: Bridge abutments have not been blown. SIGNIFICANCE: If the abutments have been blown, the increased gap length and debris in the area could increase the time estimates.

(3) ASSUMPTION: All current United States Army (USA) equipment is available to USA forces in South Korea. SIGNIFICANCE: Certain equipment such as the medium girder bridge (MGB) can save significant amounts of time.

c. Decision tree.

(1) Development. ESC used the decision tree shown in Figure 1 to select appropriate bridge responses. The decision tree is based on the range of conditions expected to be encountered along the routes and the various equipment expected to be available. Dry gaps can be crossed by military bridging which uses intermediate supports such as the Class 60 trestle used with the M4T6 fixed span, or the Bailey crib pier. However, it may not be possible to cross wet gaps with supports which rely on footings placed directly on the gap bottom, since such footings are easily undermined by flowing water. Therefore, options which required using intermediate support footings of that type were not evaluated for wet gaps. In these situations, the only

route and the bypass site, then the road length is estimated using the following equation:

$$L_r = 2 (D_r + 30)$$

[Eq 10]

where:

L_r = length of roadway constructed (m)

D_r = distance between main road and bypass (m)

(b) The time required on site is then estimated by:

$$\text{Time on Site} = (11.25) (L_r) (0.01)$$

[Eq 11]

(c) Eqs 12 and 13 are used to estimate the manhours and equipment-hours required:

$$\text{Manhours} = (195.8) (L_r) (0.01)$$

[Eq 12]

$$\text{Equipment-Hours} = (109.7) (L_r) (0.01)$$

[Eq 13]

d. Effort required to cross a wet gap. Two engineer responses were considered for wet gaps.

(1) If the water in the gap is no deeper than 0.75 m, then the gap can be forded by all military vehicles. The total work effort required to improve a potential fording site has three subtasks.

(a) Reinforcing the stream bed with aggregate to improve its load-bearing capacity. The methods used to estimate the work effort necessary to reinforce the stream bed are essentially the same as those described in paragraph 8c of this report.

(b) Widening the entrance and exit lanes to at least 5 m. If the entrance and exit lanes are less than 5 m wide, estimate the effort required to widen the lanes using the methods described in paragraph 8d of this report.

given in that document were modified by dividing each category of total work by 2. This modification takes into account that the roadway will be constructed to specifications which are less than those required for a Class C roadway, and that the roadway will be wider than one lane, but less than the two lanes considered in the E-FOSS task.

CONSTRUCTION EFFORT FOR 100 m OF ROAD

Item	Hours		No. of Items	Time On Site (Hours)
	E-FOSS*	1/2		
Grader	19.000	9.500	1	9.500
Roller, 13-Wheel	1.250	0.625	1	0.625
Tractor, Pneu Tire	1.250	0.625	1	0.625
Roller, 10-Ton	1.500	0.750	1	0.750
Dump Truck, 5-Ton	43.750	21.875	4	5.468
Dump Truck, 5-Ton, w/Dist	0.125	0.062	1	0.062
Dozer	90.000	45.000	4	11.250
Crane	2.500	1.250	1	1.250
Loader	22.500	11.250	1	11.250
Air Compressor	37.500	18.750	2	9.375
Combat Engineer	172.200	86.100	20	4.305
Total Manhours 195.787				
Total Equipment-Hours 109.687				

*E-FOSS, page N-III-ff-2.

Figure 4

(a) The last column in Figure 4 shows the time spent at the construction site by each combat engineer or item of equipment. If the road construction task is assigned to a unit composed of the particular mix of resources listed, constructing 100 m of road would require a minimum of 11.25 hours, since the construction would not be complete until the dozers and loader completed their tasks. If a distance is specified between the main

(c) If the width of the gap is less than the length of the two ramps minus 9 m, then Eq 7 is used to find the volume:

$$\text{Volume} = \frac{H^2}{12} \frac{(2H + 15)(W)}{(H - 1)} \quad [\text{Eq 7}]$$

(d) To determine a bulldozer production rate in metric measures, Table 12-2 from FM 5-34 was modified by multiplying the push distances and the production rates by appropriate metric conversion constants:⁷ (The following equation is an approximation of the resulting relationship between those two values.)

$$\frac{\text{Cubic Meters}}{\text{Dozer-Hours}} = \frac{6000}{\text{Push Distance}} \quad [\text{Eq 8}]$$

or

$$\text{Dozer-Hours} = \frac{(\text{Volume})(\text{Push Distance})}{6000}$$

(e) Estimates of the work required to move the volume of earth calculated above assume a push distance of either [(1.5) (W)] or [(15) (H)], whichever is the larger. This distance is then multiplied by 2 to account for time spent grading, shaping, and tamping the fill:

$$\text{Dozer-Hours} = \frac{(V)(W)}{2000} \text{ or } \frac{(V)(H)}{200} \quad [\text{Eq 9}]$$

(6) The estimate of work effort required to construct 100 m of roadway from the main route to the bypass site is shown in Figure 4. This estimate is based on the method described in E-FOSS, Volume VII.⁸ The data

⁷FM 5-34, p. 297.

⁸Department of the Army, US Army Training and Doctrine Command, US Army Engineer School, Combat Developments Engineer Family of Systems Study (E-FOSS), Volume VII, Appendix N--Engineer Systems Data Base, February 1979.

This equation is multiplied by 2 to estimate the volume of earth removed from both banks:

$$\text{Volume} = \frac{45 H^2 + 6 H^3}{4} \quad [\text{Eq 4}]$$

Eq 4 must be modified as the relationship between the gap width (W) and the bank height (H) varies.

(a) If the gap is wide enough, then the earth removed from the banks is exactly enough to build the two ramps. Additional earth must be used to cover the culvert. A berm composed of two wedges built on either side of the culvert would require a minimum of 45.57 m³ of earth and would be 18.3 m long. Therefore, when the width of the gap exceeds the sum of the lengths of both ramps plus 18.3 m, Eq 5 is used to estimate the total volume of fill required.

$$\text{Volume} = \frac{45 H^2 + 6 H^3}{4} + 45.57 \quad [\text{Eq 5}]$$

(b) If the gap width equals a distance less than the width defined in Eq 5 but greater than the length of the two ramps minus 9 m, then the amount of extra fill varies from 45.57 to 0.0 m³ respectively. (When the gap width is equal to the length of the two ramps minus 9 m, the fill from the two cuts is enough, by itself, to form both ramps and cover the culvert.) Eq 6 is used to approximate the total volume requirements:

$$\text{Volume} = \frac{45 H^2 + 6 H^3}{4} + \frac{45.57 (W - 9 H + 9)}{36} \quad [\text{Eq 6}]$$

minimum height of the berm. This is defined as the diameter of the pipe (0.6096 m) plus the height of the earth covering (0.3048 m):

$$\text{Minimum } L_c = 5 + 0.6096 + 2(0.6096 + 0.3048) \text{ m}$$

$$\text{Minimum } L_c = 7.4384 \text{ m}$$

(4) Work estimates for emplacing culverts were taken from ARTEP 5-35.⁶ The ARTEP says one squad of 10 men can emplace 10 ft or 3.048 m of culvert per hour. The emplacement rate, therefore, is 0.3048 m per manhour. The following equation is used to calculate the work effort required for this task:

[Eq 2]

$$\text{Manhours} = \frac{L_c}{0.3048}$$

(5) To estimate the effort needed to reduce the slope of the banks and to cover the culvert with sufficient fill, the volume of earth that must be moved is first estimated. Eq 3 is used to estimate the volume of earth removed from a 5-m wide cut which begins at the midpoint of the bank and extends back from the edge of the bank at a 10-percent grade. The sides of the cut have a slope of 45 degrees, as does the bank.

[Eq 3]

$$\text{Volume} = 5 \cdot \frac{1}{2} \cdot \frac{5}{2} \frac{H^2}{2} - \frac{1}{2} \cdot \frac{H^2}{4} \cdot 5$$

$$+ 2 \cdot \frac{1}{3} \cdot \frac{H}{2} \cdot \frac{H}{2} \cdot 5 H - \frac{1}{3} \cdot \frac{H}{2} \cdot \frac{H}{2} \cdot \frac{H}{2}$$

$$\text{Volume} = \frac{45}{8} \frac{H^2}{2} + \frac{3}{4} \frac{H^3}{2}$$

where: H = bank height

⁶Department of the Army, Headquarters, ARTEP 5-35, Combat Engineer Battalion, Corps, August 1977, pp. 3-70.

(b) Reducing the bank slopes and covering the culvert with earth.

(c) Building a road from the main road to the crossing site and back again.

(2) The length of the culvert depends on the height of the berm covering the culvert pipe. As the width of the gap decreases relative to the height of the banks, the height of the berm supporting the roadway increases. The length of pipe needed increases proportionally to the increase in the height of the berm. Assuming that the culvert is emplaced perpendicular to the axis of the road and that the sides of the berm supporting the road have a 45-degree slope, then the length of the pipe is equal to the road width (5 m) plus the downstream extension (0.6096 m) plus twice the height of the berm measured at the centerline of the pipe. Equation (Eq) 1 defines the length of culvert pipe needed. The expression $(0.9 H - 0.1 W)$ defines the height of the berm in terms of both the width of the gap and the height of its banks.

[Eq 1]

$$L_c = 5 + 0.6096 + 2(0.9 H - 0.1 W)$$

$$L_c = 5.6096 + 1.8 H - 0.2 W$$

where:

L_c = culvert length (m)

H = height of the gap's bank (m)

W = width of the gap (m)

(3) Since ESC assumed that each culvert would require at least a 0.3048-m earth covering, the minimum length of the pipe is determined by substituting for the expression $(0.9 H - 0.1 W)$, in Eq 1, the value of the

BYPASS DECISION TREE

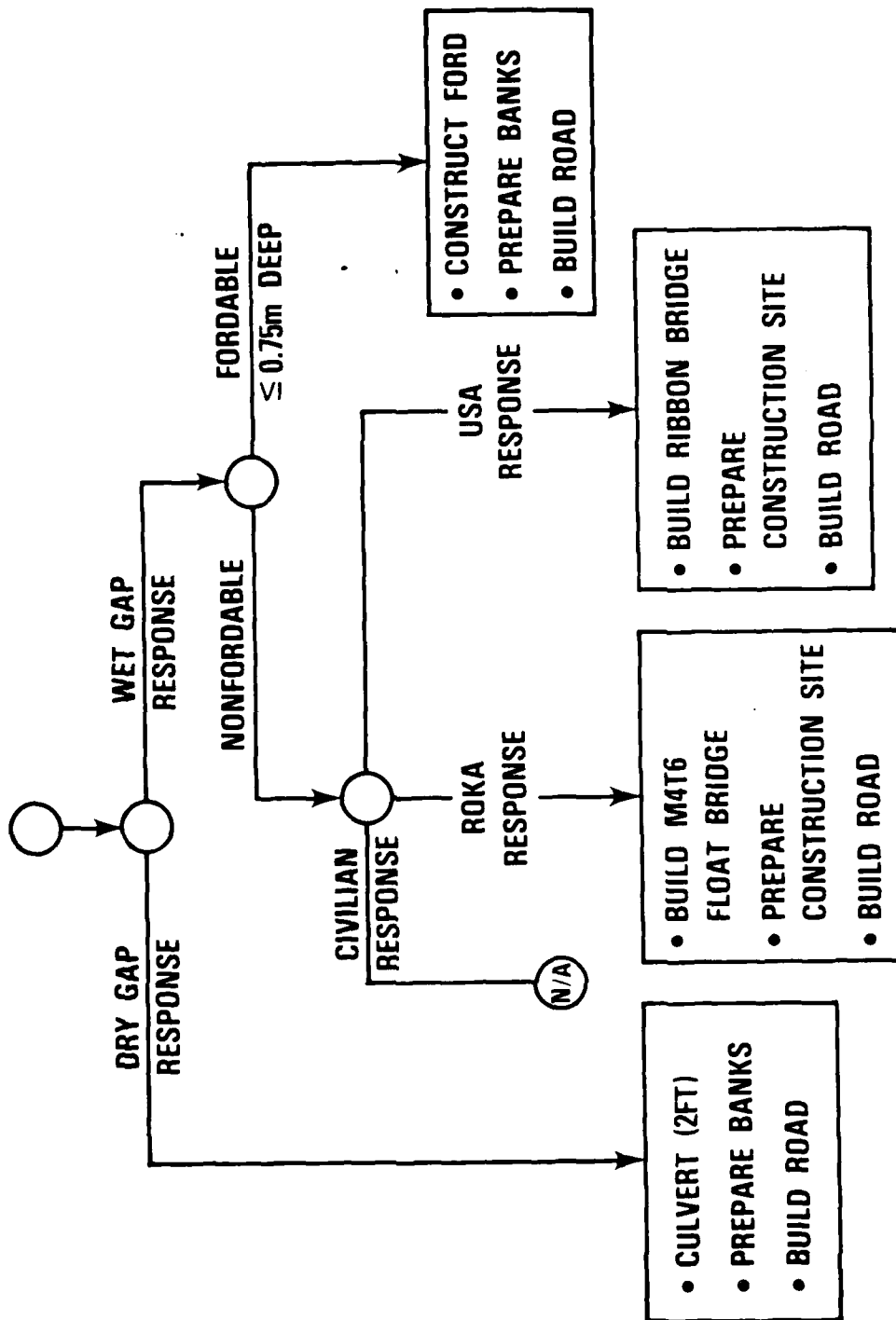


Figure 3

(8) ASSUMPTION: Roads built from the main road to the bypass will be 5 m wide and will meet lesser specifications than those required for Class C roads. SIGNIFICANCE: Road construction uses a large amount of engineer effort. These roads are built to support only the battalion or brigade trains for a short period of time. Other road improvements will be made by engineer units farther to the rear of the assaulting formations.

(9) ASSUMPTION: At least 60 m of road (30 m on each side of the gap) must be built to access the bypass, even if the bypass is adjacent to the bridge. If a lateral distance is specified in the bypass characteristics, this distance is doubled and added to the 60-m minimum length to obtain the total length requirement. SIGNIFICANCE: Unless the bypass is a ford which can be accessed by an existing road, some length of access road must eventually be built. A distance of 30 m on each side of the gap is a reasonable estimate of road length. Since road construction is an extremely time-consuming engineer task, any changes to the estimated road length will substantially increase or decrease the total work estimates.

b. Decision tree. The decision process for bridge bypasses is shown in Figure 3.

c. Effort required to cross a dry gap.

(1) The engineer effort needed to improve a dry gap crossing site includes:⁴

(a) Emplacing the culvert pipe.⁵

⁴The same estimate applies whether the involved workforce is USA, ROKA, or civilian.

⁵The use of culvert pipe is the planned method of crossing dry gap according to the Combined Forces Command.

source to the site. Loaders and possibly more dozers would be needed to load the aggregate onto dump trucks.

(3) ASSUMPTION: The slope of an unimproved gap bank is 45 degrees. SIGNIFICANCE: This is a convenient starting point for estimates. (There also is an underlying assumption that a bulldozer can negotiate the ford banks under its own power.)

(4) ASSUMPTION: Unacceptable slopes are reduced by using earth removed from the top of the bank as fill to form a ramp extending from the midpoint of the bank to the floor of the river bed. SIGNIFICANCE: This method is an acceptable engineer alternative. Other alternatives may increase or decrease the amount of earthmoving required.

(5) ASSUMPTION: Culverts are built using corrugated, nestable pipe 0.6096 m (2 ft) in diameter. A 0.6096-m extension is built on the downstream side of the roadway to minimize scouring. SIGNIFICANCE: The size of the culvert pipe depends on the amount of precipitation anticipated and the drainage characteristics of the surrounding terrain. ESC chose a 2-ft pipe diameter as an average size.

(6) ASSUMPTION: Culverts must be covered with at least 0.3048 m (1 ft) of earth. SIGNIFICANCE: All culverts are built from 12-gauge pipe. (The 1-ft minimum earth covering standard is taken from TM 5-330).³

(7) ASSUMPTION: Culverts are built without headwalls. SIGNIFICANCE: Building headwalls requires extensive effort, and would dramatically increase the total effort estimates.

³Department of the Army, Headquarters, TM 5-330, Planning and Design of Roads, Airbases, and Heliports in the Theater of Operations, September 1968, pp. 6-42.

BRIDGE ESTIMATING FORMULAS

USA Bridging Response

<u>Length (m)</u>	<u>Crew Size</u>	<u>Time (hr)</u>	<u>Manhours*</u>
$L_b < 18$	2	0.1	0.2
$18 < L_b < 30$	25	1.5	25
$30 < L_b$	39	$3.7 + [0.02785 (L_b)]$	$34.6 + [1.71 (L_b)]$

*Note: Manhours were not derived by simply multiplying crew size by time. The crew size is a peak requirement; there will be other times when portions of the crew will be available for other tasks.

ROKA Bridging Response

<u>Length (m)</u>	<u>Crew Size</u>	<u>Time (hr)</u>	<u>Manhours*</u>
$L_b < 11.6$	14	0.5	7
$L_b > 11.6$	32	$1.81 + [0.07781 (L_b)]$	$8.76 + [2.28 (L_b)]$

*Note: Manhours were not derived by simply multiplying crew size by time. The crew size is a peak requirement; there will be other times when portions of the crew will be available for other tasks.

Civilian Bridging Response

<u>Length (m)</u>	<u>Crew Size</u>	<u>Time</u>	<u>Manhours</u>	<u>Short Tons</u>
$L_b < 18.3$	20		(see formulas below)	
$L_b > 18.3$	52		(see formulas below)	

$$\begin{aligned} \text{Time (hr)} &= 15.39 + [0.993 (L_b)]^{**} \\ \text{Manhours} &= -53.51 + [28.48 (L_b)]^{**} \\ \text{Short Tons} &= -3.29 + [3.148 (L_b)]^{**} \end{aligned}$$

**The original estimates used to develop these formulas were based on a letter from Department of the Army, US Army Corps of Engineers, Facilities Engineering Support Agency, AFCs Labor and Equipment Estimates, 28 November 1977. The formulas were derived by linear regression.

Figure 2

(2) ASSUMPTION: Aggregate, normally in the form of sand, is available at the bypass site. SIGNIFICANCE: If material is not available locally, then additional effort is required to haul the aggregate from its

the minimum levels required to construct the bridges. While larger crews could reduce construction times, the overcrowding that results at small sites reduces efficiency.

(2) Bridge formulas and data. The data and formulas shown in Figure 2 were used to develop the engineer estimates contained in the ESC study.

7. Bridge Bypasses.

a. General assumptions and Their Significance.

(1) ASSUMPTION: All banks are reduced to a 10-percent grade to allow the uninhibited passage of combat support and support vehicles and to keep roadway erosion to a minimum. SIGNIFICANCE: An increase in the maximum allowable slope will substantially lessen the amount of earthmoving required at the bypass site.

constructed using steel piles and pile-driving equipment available from local construction firms. The designs for the civilian bridges are based on the Technical Manual (TM) 5-302-3.¹

(2) Using the decision tree. The decision tree is designed for use by the analysts who perform the engineer route analyses. It leads the analysts through a sequence of simple questions to the selection of the proper bridging equipment for a gap.

d. Calculation formulas.

(1) Development. Initially, ESC based all calculations on the equations and charts in Field Manual (FM) 90-13, FM 5-34, TM 5-210, TM 5-277, Army Training and Evaluation Program (ARTEP) 5-64, and other references.² However, it soon became clear that a more general, quicker method could be developed which would be equally valid. The calculated bridge data for Route B were grouped according to the available equipment and a linear regression was run. The result was a set of formulas which predict the construction times and manhours required for longer bridges. For shorter bridges, it was found that within certain ranges, time and manhour requirements do not change much. Also, the quantity of material required for civilian construction of a particular bridge could be predicted. Crew size was not a smooth function of bridge length, because crew estimates are based on the number of men required to carry the larger bridge components. Therefore, a crew sizes were set at

¹Department of the Army, Headquarters, TM 5-302-3, Army Facilities Components Systems--Designs, Volume III, 31 May 1979.

²Department of the Army, Headquarters, FM 90-13, River Crossing Operations, November 1978; FM 5-34, Engineer Field Data, September 1976; TM 5-210, Military Floating Bridge Equipment, August 1970; TM 5-277, Bailey Bridge, August 1972; and ARTEP 5-64, Engineer Bridge Companies, June 1978.

remaining option is to use another force with different equipment or to use a bypass.

(a) USA equipment. Equipment is not limited to just that now available to USA forces in South Korea. All engineer bridging equipment available to USA forces elsewhere is considered available in South Korea. The MGB is used often in this analysis because it can be rapidly installed with a small crew. The Bailey bridge can be substituted for the MGB; however, it takes longer to install and larger crews are needed to assemble it. The cable reinforcing kit is used extensively in this analysis, since it reduces the effort required to build a long (greater than 30.5 m) bridge. The armored vehicle launched bridge (AVLB) is used for gaps of up to 18 m. From 18 to 30.5 m, the MGB is used. From 30.5 to 48.8 m, the MGB with cable reinforcing kit is used. From 48.8 to 54.8 m, a Bailey bridge with a cable reinforcing kit is used. For bridges longer than 54.8 m, an MGB is used with intermediate piers built using Bailey bridge components; this option is only used over dry gaps for the reasons mentioned above.

(b) Republic of Korea Army (ROKA) equipment. The only specialized military bridging equipment available to the ROKA is the M4T6 and the Class 60 float bridge. Thus, the maximum gap the ROKA can span without intermediate supports is 11.6 m. For gaps greater than 11.6 m, the Class 60 or Universal trestle arrangements must be used (the trestle option is used only over dry gaps).

(c) Civilian equipment. South Korean civilian bridging equipment is mainly steel stringers and steel piles. For gaps up to 18.3 m, steel stringers without intermediate supports are considered adequate for Class 60 loads. For gaps greater than 18.3 m, intermediate supports must be

```

graph LR
    BR[BRIDGE RESPONSE] --> WG[WET GAP (m)]
    BR --> DG[DRY GAP (m)]
    WG --> WG_USA[USA EQUIPMENT]
    WG --> WG_ROKA[ROKA EQUIPMENT]
    WG --> WG_CIV[CIVILIAN EQUIPMENT]
    DG --> DG_USA[USA EQUIPMENT]
    DG --> DG_ROKA[ROKA EQUIPMENT]
    DG --> DG_CIV[CIVILIAN EQUIPMENT]
    WG_USA --> WG_USA_L1["L < 18"]
    WG_USA --> WG_USA_L2["18 < L < 30.5"]
    WG_USA --> WG_USA_L3["30.5 < L < 48.8"]
    WG_USA --> WG_USA_L4["48.8 < L < 54.8"]
    WG_USA --> WG_USA_L5["L > 54.8"]
    WG_USA_L1 --> WG_USA_L1_EQ[AVLB]
    WG_USA_L2 --> WG_USA_L2_EQ[MGB]
    WG_USA_L3 --> WG_USA_L3_EQ["MGB-REINF"]
    WG_USA_L4 --> WG_USA_L4_EQ["BAILEY-REINF"]
    WG_USA_L5 --> WG_USA_L5_EQ[BYPASS]
    WG_ROKA --> WG_ROKA_L1["L < 11.6"]
    WG_ROKA --> WG_ROKA_L2["L < 11.6"]
    WG_ROKA_L1 --> WG_ROKA_L1_EQ[BYPASS]
    WG_ROKA_L2 --> WG_ROKA_L2_EQ["MATB or CLB"]
    WG_CIV --> WG_CIV_L1["L < 18.3"]
    WG_CIV --> WG_CIV_L2["L < 18.3"]
    WG_CIV_L1 --> WG_CIV_L1_EQ[SS]
    WG_CIV_L2 --> WG_CIV_L2_EQ["SS & SPB"]
    DG_USA --> DG_USA_L1["L < 18"]
    DG_USA --> DG_USA_L2["18 < L < 30.5"]
    DG_USA --> DG_USA_L3["30.5 < L < 48.8"]
    DG_USA --> DG_USA_L4["48.8 < L < 54.8"]
    DG_USA --> DG_USA_L5["L > 54.8"]
    DG_USA_L1 --> DG_USA_L1_EQ[AVLB]
    DG_USA_L2 --> DG_USA_L2_EQ[MGB]
    DG_USA_L3 --> DG_USA_L3_EQ["MGB-REINF"]
    DG_USA_L4 --> DG_USA_L4_EQ["BAILEY-REINF"]
    DG_USA_L5 --> DG_USA_L5_EQ["MGB/PIER"]
    DG_ROKA --> DG_ROKA_L1["L < 11.6"]
    DG_ROKA --> DG_ROKA_L2["L < 11.6"]
    DG_ROKA_L1 --> DG_ROKA_L1_EQ["MATB/ TRESTLE"]
    DG_ROKA_L2 --> DG_ROKA_L2_EQ["MATB or CLB"]
    DG_CIV --> DG_CIV_L1["L < 18.3"]
    DG_CIV --> DG_CIV_L2["L < 18.3"]
    DG_CIV_L1 --> DG_CIV_L1_EQ[SS]
    DG_CIV_L2 --> DG_CIV_L2_EQ["SS & SPB"]
  
```

MGB -- MEDIUM GIRDER BRIDGE

SS - STEEL SPAN

SP8 - STEEL PILE BENT

REINF - CABLE REINFORCING KIT USED

BYPASS - TRETTLES AND PIERS PROBABLY CANNOT BE PLACED IN GAPS WITH FLOWING WATER

CL60 - CLASS 60

L - LENGTH OF GAP

Figure 1

(c) Constructing a road to the bypass site. This task is defined and the effort estimated using the techniques described in paragraph 7c(6) of this paper.

(2) If the water in the gap is deeper than 0.75 m, then float bridging equipment is used. As shown in Figure 5, the availability of specific categories of float bridging depends on whether a USA or ROKA engineer unit responds.

AVAILABILITY OF BRIDGING

Bridging	USA	ROKA
Ribbon	yes	no
Class 60	yes	yes
M4T6	yes	yes

Figure 5

(a) A civilian response is not considered an option at a bypass site. Effort required for a civilian response has been estimated using the methods described in paragraph 6 of this report.

(b) ESC developed work estimates for three bridging categories for each deep-water bypass site. The best bridging method was chosen based on the shortest response time between bridge categories. If the difference in time requirements was minimal, then the bridging method requiring the smallest crew was chosen.

e. Work estimates for ribbon bridges. The total response time is calculated using a construction factor of 150 m per hour. Different references provide different factors up to 200 m per hour; 150 m per hour was selected as a conservative but realistic estimating factor.

(1) The number of interior bays required to span the gap is estimated using a formula taken from the TRADOC Planning Guide:⁹

[Eq 14]

$$\text{Number of Interior Bays} = \frac{\text{Gap Width (m)} - 14}{6.7}$$

(2) Crew size estimates are based on a 50-man bridge platoon. Each platoon is assigned 10 interior bays, 4 ramp bays, and 6 bridge erection boats. A reinforced section of 25 men is the smallest unit that can support a ribbon bridge crossing site.

f. Work estimates for the M4T6 float bridge. TM 5-210 lists many different construction times for the M4T6 float bridge. These times vary from 11 to 45 m per hour; 37.5 m per hour was selected as a realistic estimate of normal assembly speed. Since the manual states that construction with pre-assembled bays doubles the construction speed, 75 m per hour was used in the ESC calculations.

(1) The number of bridge floats required to span the water gap is estimated using the equation for a reinforced bridge given in the Planning Guide:

[Eq 15]

$$\text{Number of Floats} = \frac{\text{Gap Width (m)}}{3} + 10\%$$

(2) The number of assembly sites required to construct the bridge was taken from Table 6-6 of TM 5-210. The number of assembly sites is used to estimate the number of construction platoons (one per site), the number of bridge company sections (one per site), and the number of bridge erection boats (two per site). The standard size of a construction platoon is 36 men. The standard size of a bridge company section is 22 men. When two

⁹Department of the Army, US Army Training and Doctrine Command, US Army Engineer School, Planning Guide for the Use of U.S. Army Floating Equipment, Fall 1980, p. 12 (hereafter referred to as Planning Guide).

bridge company sections are combined, 11 more men are added to form a 55-member platoon.

(3) Although the floats arrive at the crossing site preassembled, one crane is needed at the crossing site to help with heavy lifting.

g. Work estimates for the Class 60 float bridge. The construction factors for the Class 60 float bridge are 27.4 m (90 ft) the first hour and 36.5 m (120 ft) every hour thereafter.¹⁰

(1) The number of floats required to span the water gap is calculated using the formula found on page 8 of the Planning Guide:

$$\text{Number of Floats} = \frac{\text{Gap Width (m)}}{3} + 10\% \quad [\text{Eq 16}]$$

(2) The number of launching sites required is taken from the table on page 8 of the Planning Guide:

River Width (m)	Number of Sites
0 - 75	2
76 - 103	3
104 - 131	4
132 - 160	5
161 - 300	6

(3) The number of personnel needed at the bypass site to construct the bridge is estimated using Table 7-4 of TM 5-210. When the trestle crew is omitted (per note (a) in Table 7-4 of TM 5-210), 83 crew members are needed for one construction site. Crew size is increased for additional sites by:

¹⁰These values are taken from pp. 7-14 of TM 5-210.

[Eq 17]

$$\text{Crew} = 61 (n) + 22$$

where: n = number of launching sites.

The value 22 in Eq 17 represents the command group (2), the bridge assembly crew (9), and the anchorage crew (11). Only one of each of these crews is needed at the bypass site.

(4) ESC estimated that one crane and one bridge erection boat are needed at each site.

8. Fords.

a. General assumptions and Their Significance.

(1) ASSUMPTION: Since this study only identified active fords used by civilian vehicles, no engineer effort is required to assist combat vehicles during the assault crossing. SIGNIFICANCE: It is unlikely that the assault forces would require engineer assistance to cross a water gap at a ford site currently used by civilian vehicles.

(2) ASSUMPTION: Aggregate, normally in the form of sand, is available at the ford site. Work effort calculations assume a push distance equal to 120 percent of the water gap width. SIGNIFICANCE: If appropriate aggregate is not available at the site, then dump trucks are required to move the aggregate to the ford site. More dozers and loaders may also be needed at the aggregate site to load the aggregate onto the trucks.

(3) ASSUMPTION: The slopes of the entrance and exit lanes to and from the ford sites will support military traffic. SIGNIFICANCE: If the slopes must be reduced by dozer, this effort increases the stated estimates. However, since the existing slopes can be negotiated by civilian vehicles, they should not hinder military vehicles.

(4) ASSUMPTION: A crossing lane of at least 5 m is needed by vehicles attached to the battalion and brigade trains. SIGNIFICANCE: ESC chose 5 m as a mean road width to be compatible with a 5-m wide roadway.

(5) ASSUMPTION: Only one lane is prepared at the crossing site. SIGNIFICANCE: Preparing two lanes requires additional effort. Such work should be assigned to engineer units farther to the rear of the assaulting forces.

(6) ASSUMPTION: The ford banks are 2 m high. SIGNIFICANCE: ESC chose 2 m as a mean height. Unless the difference is very large, increases or decreases to this height will have little effect on the overall effort.

(7) ASSUMPTION: The slope of access and egress banks at the ford sites is 10 percent. SIGNIFICANCE: No engineer work is required to improve these grades.

b. Decision tree. Figure 6 shows the method used to estimate engineer effort at the ford sites.

c. Effort required to reinforce the stream bed with aggregate.

(1) The aggregate is spread to a thickness of 0.3 m. Besides covering that area of the river bed extending from waterline to waterline, the aggregate also covers an area along both banks extending out from the waterline for a distance equal to 10 percent of the width of the water gap. The total amount of aggregate required is calculated using the equation for the volume of a rectangular solid:

[Eq 18]

$$\text{Volume} = L [(1.2) (W)] 0.3$$

$$\text{Volume} = 5 [(1.2) (W)] 0.3$$

$$\text{Volume} = (1.8) (W)$$

FORD DECISION TREE

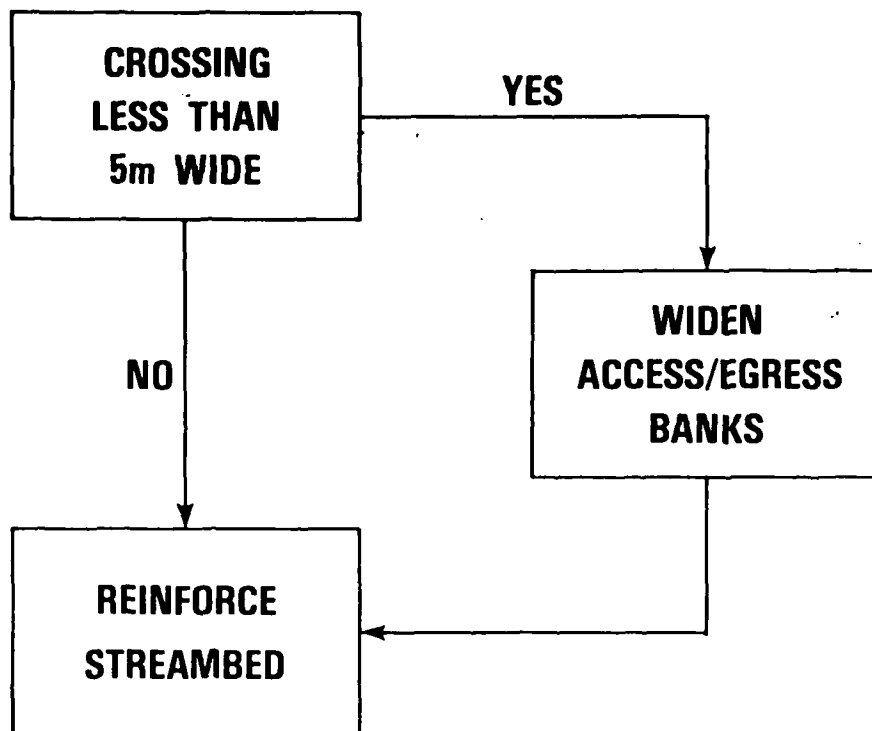


Figure 6

where:

L = width of ford lane (m)

W = width of water gap (m)

(2) To determine a bulldozer production rate, a push distance of 1.2 W is substituted into Eq 8:

$$\text{Dozer-Hours} = \frac{(\text{Volume})(W)}{5000} \quad [\text{Eq 19}]$$

(3) The work team includes one dozer operator and two combat engineers to do the manual labor (e.g., tamping and lane marking). The total number of manhours required to prepare the ford river bed is estimated by multiplying the bulldozer hours by 3.

d. Effort required to widen the cut in the river bank to a minimum width of 5 m.

(1) The volume of the material removed from one river bank by the bulldozer is estimated by using the equation for a triangular solid:

$$\text{Volume} = 1/2 [(L)(W)(H)]$$

where:

L = length of cut (m)

W = additional width of cut to be removed (m)

H = height of bank (m)

(a) If L = 10 (H), W = 5 m - (width of the ford lane), and H = 2 m, then:

$$\text{Volume} = 100 - 20 (\text{width of ford lane}) \quad [\text{Eq 20}]$$

(b) Multiplying by 2 accounts for the work performed on both banks:

[Eq 21]

Volume = 200 - 40 (width of ford lane)

(2) The number of dozer-hours required is estimated using Eq 19.

(3) This task requires one dozer operator; thus, the number of manhours expended equals the number of dozer-hours expended.

9. Manmade Obstacle Systems.

a. Overview. Obstacle systems are uniquely situated on specific terrain to maximize the delay of an attacking force. Most of the obstacles encountered along normal routes are simple structures which are overcome by a fairly obvious, straightforward response. However, a few can be complex systems which must be carefully examined to find their weaknesses. On the routes in the ESC study, tank ditches and berms were often the only obstacles. Even when obstacle systems were examined, the ditches and berms seemed to be the weak link when compared to massive concrete overhead and side drops or fields of dragon's teeth. In the initial breach, only a minimum amount of work was usually required to get the assault vehicles through the obstacle. However, the follow-on battalion and brigade trains needed an improved lane with gentle slopes and a smooth surface.

b. Assumptions and Their Significance.

(1) ASSUMPTION: Aggregate and fill material will be available in the immediate vicinity of the obstacle. SIGNIFICANCE: No significant time is required to haul fill to the obstacle site. If no fill is immediately available, the time estimates will have to be increased.

(2) ASSUMPTION: Attacking forces need a lane at least 3.5 m wide. SIGNIFICANCE: Wider lanes will slow down the engineer effort. The follow-on effort will increase this width to 5 m to support the forward movement of vehicles in the unit trains.

c. Selecting lanes to be cleared. In most cases, selecting a lane is simply a matter of finding the easiest path to the obstacle (usually a ditch) and crossing it in the most direct manner. However, complex systems must be carefully examined to determine the best path through them. The obstacle descriptions developed for the ESC study should make this assessment easier. The particular set of choices recommended reflect the subjective opinion of ESC's analysts. Other alternatives are equally valid.

d. Calculations.

(1) Berms and levees. Essentially, only an earthmoving effort is required to reduce berms and levees. The earthmover reduces a section of berm to a 10-percent slope, making it negotiable by most military vehicles. The calculations below consider the volume of the berm to be cut and the amount of dozer effort required to move the earth.

(a) The volume of a berm cut can be broken into four types. The first type has two wedges on the near and far side of the berm. The second type has four pyramids on the sides of the wedges. The third type has a center rectangular parallelopiped. The fourth type has two prisms, one on each side of the parallelopiped. For the ESC study, the angle of repose was assumed to be 45 degrees. This allowed the height and base of triangular volumes to be the same measurement. Figures 7 and 8 show how to calculate a value for each volume type.

(b) The volume of the reduced berm is calculated as shown in Figure 7. This berm is assumed to peak at the top, so the length of the cut (T_b) is 0. As a result, volumes V3 and V4 also equal 0.

(c) The volume to be removed is calculated by incrementally increasing the height of reduced berm (I) and then comparing the resulting

VOLUME OF A BERM CUT

Volume of Earth Removed

Two Center Wedges

$$V1 = W_b (H_b - I)^2$$

Four Pyramids

$$V2 = \frac{2}{3} (H_b - I)^3$$

Parallelopiped

$$V3 = (W_b) (T_b) (H_b - I)$$

Two Prisms

$$V4 = (T_b) (H_b - I)^2$$

$$\text{Total Volume} = V1 + V2 + V3 + V4$$

Volume of Berm Remaining

Two Center Wedges

$$V_a = 10 (W_b) (I)^2$$

Four Pyramids

$$V_b = \frac{20}{3} (I)^3$$

$$\text{Total Volume} = V_a + V_b$$

Definitions

- W_b = width of cut (normally 3.5 m for the assault breach)
 T_b = length of cut (from near to far sides measured at the top of the berm)
 H_b = height of berm
 I = height of reduced berm

Figure 7

BERM CUT DIAGRAMS

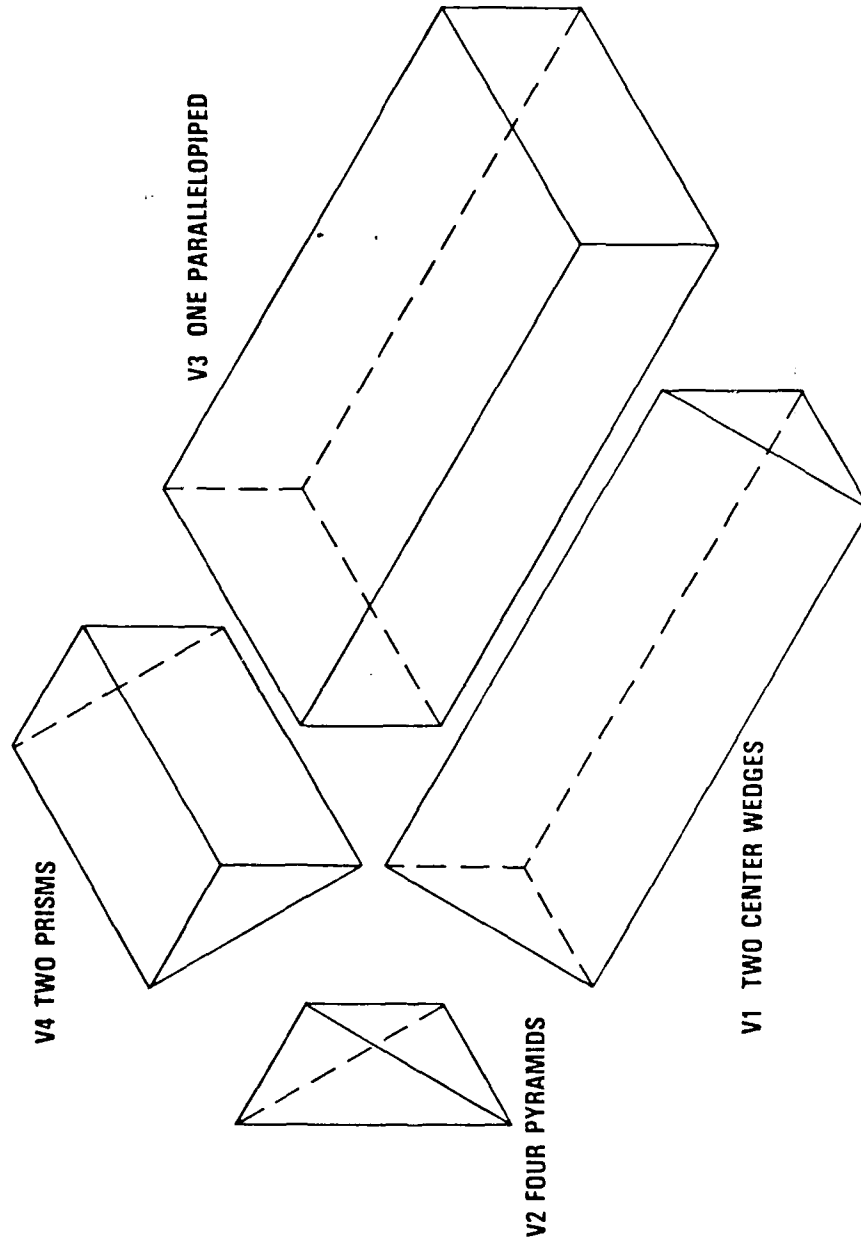


Figure 8

volume of earth removed against the volume of berm remaining. When these two volumes are equal, then the calculations are complete.

(d) The dozer-hours required to move this volume of material are calculated using Eq 8. The push distance used is twice the length of the base of the berm. (This allows enough area for piling or spreading.) However, unlike the estimates for bypasses, this push distance is not multiplied by 2, since shaping and grading are not required for assault lanes.

(2) Tank ditches. The volume of earthwork required to cross a tank ditch is calculated by comparing the volume of fill placed in the ditch to the volume of fill removed from the sides of the ditch. The earth removed from the sides of the ditch is pushed into the ditch. There it forms a berm over which vehicles can cross. Mathematically, incremental slices of the banks are removed until the total volume of earth removed from the banks equals the volume of earth within the ditch which forms the crossing berm. This volume is the one used for work estimates. Figure 9 shows the volumes for typical ditches encountered on the routes considered in the ESC study.

TANK DITCH EARTHWORK REQUIREMENTS

Ditch Width (m)	Ditch Depth (m)	Total Volume of Earthwork (m ³)
3	2	19
5	3	51
7	3	66
7	5	150
9	3	78
9	5	179

Figure 9

(a) The push distance is the average distance between the cut on the bank and the fill in the ditch;

$$\text{Push Distance} = [(1/2) (W_d)] + [5 (D - H_d)]$$

[Eq 22]

where:

D = depth of the ditch,
 W_d = width of the ditch, and
 H_d = height of the fill in the ditch

(b) The dozer-hours are calculated using Eq 8.

(3) Boulder Fields. USA forces use CEVs to clear boulder fields, while the ROKA and civilian forces use bulldozers.

(a) Estimate the number of boulders that must be removed. The boulders are assumed to be arranged in a checkerboard pattern. The required lane width for the breach is assumed to be 3.5. The following test is applied to each boulder field in order to estimate the number of boulders that must be removed:

If $2 (S) + (W) > 3.5$, then remove one boulder per row

If $2 (S) + (W) < 3.5$, then remove two boulders per row

where:

S = spacing between boulders in meters

W = width of boulders in meters.

(b) Estimate the time required for a crew, using the CEV's main gun, to break up the boulders. To account for misses and those rounds that do not break up a boulder sufficiently, one and one-half rounds are planned for every boulder. Assume that it requires 1.5 minutes to load, aim, and fire each round. The following equation is used to estimate the time required:

$$\text{Time} = (\text{Number of targets}) (1.5 \text{ rounds/target})$$

(0.025 hours/round)

[Eq 23]

$$\text{Time} = (\text{Number of targets}) (0.0375)$$

Assume that a dozer can clear 1000 square yards in 1.8 hours¹¹ and that a CEV is only 80 percent as efficient as a dozer. The following equation is used to estimate the time needed by the CEV to clear the remaining debris:

[Eq 24]

$$\text{Time} = W (3.5/836.1) (2.25)$$

where W = width of the field of obstacles

2.25 = 1.8/0.8 converting dozer efficiency to CEV efficiency

836.1 = metric conversion

3.5 = required lane width

The total time expended is estimated by combining both of the above equations.

[Eq 25]

$$\text{Total Time} = (\text{Number of targets}) (0.0375) + (W) (0.0094)$$

(c) Estimate the time required for a dozer to remove the boulders. Assume that it takes 0.3 hours to remove a boulder using a dozer. The following equation estimates the total time required for a dozer to clear a boulder field:

$$\text{Total Time} = (\text{Number of boulders}) (0.3)$$

(4) Concrete side drops. Time and resource requirements were estimated for two methods: explosives and earthmoving.

¹¹TM 5-333, pp. 6-3, Figure 6-1.

ANNEX

BASIC PROGRAM FOR ENGINEER MOBILITY ESTIMATES

<u>Paragraph</u>		<u>Page</u>
1	Purpose	A-1
2	Scope	A-1

1. Purpose. This annex lists a computer program, written in Basic language, which will calculate the combat engineer support required to overcome various man-made obstacles.

2. Scope. This program uses the equations and methods discussed in paragraph 9 of the report to calculate work estimates. The program is written in generic Basic programming language. However, it must be modified in order for it to run correctly on any particular computer. For example, the notation "*Clear Screen*" at lines 160, 1010, 2010, 3010, 4010, and 5010 will have to be changed to the particular machine convention which clears the screen of characters. In some instances, the single quotation mark must be replaced with a double quotation mark. Any such adjustments are minor--most of the program can be typed into any computer, including small personal computers like the Apple IIe, as shown.

ANNEX

BASIC PROGRAM FOR ENGINEER MOBILITY ESTIMATES

W_r = Width of river

X = Number of concrete side drops

LAST PAGE OF MAIN PAPER

e. **LEGEND**

D_r = Distance from the main road to the bypass
 D = Depth of ditch
 DH = Dozer-hours
 EH = Equipment-hours
 H = Height of gap banks
 H_b = Height of berm or levee
 H_d = Height of fill forming the crossing berm in the ditch
 I = Height of the remaining berm
 L = Lane width of crossing
 L_b = Length of bridge
 L_c = Length of culvert
 L_r = Length of road
 MH = Manhour
 n = Number of assembly sites
 s = Distance from front of first block to rear of last block.
 S_f = Spacing between boulders
 ST = Short tons of materiel
 T = Total time at the site
 T_b = Thickness of berm measured across its top
 V_f = Volume of fill necessary
 V = Volume of earth moved
 W = Width of the gap/field of obstacles
 W_b = Width of the cut in a berm or levee
 W_d = Width of the ditch measured from near to far side
 W_f = Width of individual boulder.

(3) Boulder Fields

If $2 (S_f) + W_f > 3.5$, remove one boulder
per row

If $2 (S_f) + (W_f) < 3.5$, remove two
boulders per row

CEV: Time = (number of targets) $(0.0375) + W_f$
 (0.0094)

Dozer: Time = (number of targets) (0.03)

(4) Concrete Side Drops

Explosives: Detonate breaching charge for one
block = 68 minutes

Detonate breaching charge for more than one
block = $37 + 33(X)$ minutes

Loader: $\frac{X (6.75)}{(150) (0.765)}$

Earthmoving:

Volume = $112.5 + 6(S) + 2.25 (S) - 6.75(X)$

d. MANMADE OBSTACLES

(1) Berms and Levees (USA, ROKA, and Civilian)

Volume of Earth Removed from Original Berm/Levee:

$$\text{Two Center Wedges} = V1 = (W_b) (H_b - I)^2$$

$$\text{Four Pyramids} = V2 = \frac{2}{3} (H_b - I)^3$$

$$\text{Parallelopiped} = V3 = (W_b) (T_b) (H_b - I)$$

$$\text{Two Prisms} = V4 = (T_b) (H_b - I)^2$$

Volume of Remaining Berm (10% Slopes):

$$\text{Two Center Wedges} = V_a = 10 (W_b) (I)^2$$

$$\text{Four Pyramids} = V_b = \frac{20}{3} (I)^3$$

$$\text{Push Distance} = 2 (2 H_b + T_b)$$

$$DH = \frac{(V_1 + V_2 + V_3 + V_4) (\text{Push Distance})}{6000}$$

(2) Tank Ditches

Volume Calculations

W_d	D	V_f
3	2	19
5	3	51
7	3	66
7	5	150
9	3	78
9	5	179

$$\text{Push Distance} = \frac{W_d}{2} + 5 (D - H_d)$$

$$DH = \frac{(V_f) (\text{Push Distance})}{6000}$$

(3) Float Bridging--Continued

Class 60 Float Bridge Construction:

Time Estimates

W_r	T
< 27.4	$\frac{W_r}{27.4}$
> 27.4	$1 + \frac{W_r - 27.4}{36.5}$

Number of Floats = $\frac{W_r}{3} + 10\%$

Assembly Sites Required

W_r	Number of Sites
0 - 75	2
76 - 103	3
104 - 131	4
132 - 160	5
160 - 300	6

Required per Site

Erection Boats	1
Cranes	1
Crew	$61(n) + 22$

Road Construction

$L_r = 2(D_r + 30)$	$MH = 1.958(L_r)$
$T = 0.1125(L_r)$	$EH = 1.097(L_r)$
	Crew = 47

(3) Float Bridging

Wet Gap--Unfordable (USA and ROKA Only)

Ribbon Bridge Construction (USA Only):

$$T = \frac{W_r}{150}$$

$$\text{Number of Interior Bays} = \frac{W_r - 14}{6.7}$$

Ribbon Bridge Section	
Crew	25
Interior Bays	5
Ramp Bays	2
Erection Boats	3

M4T6 Float Bridge Construction:

$$T = \frac{W_r}{75}$$

$$\text{Number of Floats} = \frac{W_r}{3} + 10\%$$

Assembly Sites Required

W_r	Number of Sites
< 45.5	1
45.5 - 91.5	2
91.5 - 122	3
122 - 152	4
152 - 183	5
183 - 366	6

Required per Site

Erection Boats	2
Construction Platoon	1 (36 men)
Bridge Section	1 (22 men)*

*For every two bridge sections, add 11 additional men to form a 55-man platoon.

c. **BYPASSES**

(1) **Culverts**

Dry Gap (USA, ROKA, and Civilian)

Culvert Emplacements:

$$L_c = 5.6096 + 1.8 H - 0.2 W$$

$$L_c \text{ (Minimum)} = 7.4384$$

$$MH = \frac{L_c}{0.3048}$$

Earthmoving Requirements:

Volume Calculations

W	V	
$> 9 H + 18.3$	$\frac{45 H^2 + 6 H^3}{4}$	+ 45.57
$9 H + 18.3$ to $9 H - 9$	$\frac{45 H^2 + 6 H^3}{4}$	+ $\frac{45.57 (W - 9 H + 9)}{36}$
$< 9 H - 9$	$\frac{H^2 (2 H + 15) (W)}{12 (H - 1)}$	
$DH = \frac{(V) (W)}{2000} \text{ or } \frac{(V) (H)}{200}$		

(2) **Fording**

Wet Gap--Fordable (USA, ROKA, and Civilian)

Reinforce Stream Bed:

$$V_f = 1.8 (W)$$

$$DH = \frac{(V_f) (W)}{5000} \quad MH = 3 (DH)$$

Widen Cut in Bank ($L < 5$):

$$V = 40 (5 - L) \quad DH = MH = \frac{(V) (W)}{5000}$$

a. BRIDGES

USA Response

L_b	Crew	T	MH
< 18	2	0.1	0.2
18 TO 30	25	1.5	25.0
> 30	39	$3.7 + [0.02785 (L_b)]$	$34.6 + [1.71 (L_b)]$

ROKA Response

L_b	Crew	T	MH
< 11.6	14	0.5	7.0
> 11.6	32	$1.81 + [0.07781 (L_b)]$	$8.76 + [2.28 (L_b)]$

Civilian Response

L_b	Crew	T	MH	ST
< 18.3	20	(see formulas below)		
> 18.3	52	(see formuals below)		

$$T = 15.39 + [0.993 (L_b)]$$

$$MH = -53.51 + [28.48 (L_b)]$$

$$ST = -3.29 + [3.148 (L_b)]$$

b. FORDS

Reinforce the Stream Bed (USA, ROKA, and Civilian)

$$V_f = 1.8 (W)$$

$$DH = \frac{(V_f) (W)}{5000} \quad MH = 3 (DH)$$

Widen Cut in Bank ($L < 5$)

$$V = 40 (5 - L) \quad DH = MH = \frac{(V) (W)}{5000}$$

is estimated as twice the obstacle width. 0.6 hours is added to account for the time necessary for the trucks to dump enough fill to begin using the dozer and the time spent compacting the fill. The resulting equation is:

$$DH = 0.6 + \frac{(V) (1.59) (S) (2)}{6000} \quad [Eq\ 29]$$

e. Roads. After the initial assault breach, more effort must be spent to improve the lane for the unit trains. In the ESC study, the follow-on effort for obstacles is a low-quality, 5-m wide road designed to last just a few hours. This road is expected to follow the lane previously cleared through the obstacle. In the case of simple obstacles, the road may be as short as 10 m, which is expected to be a typical minimum length necessary to get around a destroyed culvert or other road obstruction. For more complex obstacle systems, the road may be considerably longer. The calculations for engineer follow-on effort are given in paragraph 7c(6) of this paper.

10. Summary of Formulas. For ease of reference, the formulas derived and discussed in this paper are listed on the following pages.

clear loose earth. The work factor of 300 cubic yards per hour found in FM 5-34, Table 12-4, is divided by 2 to reflect this difference. The following equation is used:

[Eq 27]

$$\text{Loader hours} = \frac{(2) (X) (6.75)}{(300) (0.765)}$$

Where x = number of blocks
 6.75 = volume of a block
 0.765 = metric conversion factor.

(b) Earthmoving. Dump trucks are used to carry fill to the obstacle site. Dozers are used to build ramps on both sides of the obstacle and to fill the gaps between the blocks.

1. The equations used to estimate the volume of fill required are similar to those used for berms and levees. After the total volume of the cut plus the two ramps is estimated, the volume of the blocks is subtracted to determine the volume of fill required. The resulting equation used for fill estimates is:

[Eq 28]

$$\text{Volume} = 112.5 + 6(S) + 2.25(S) - 6.75(X)$$

Where X = number of blocks
 S = distance from front of first block to rear of last block (obstacle width).
 6 = Estimated volume of all side drop gaps.
 112.5 = Constant volume of access and egress ramps 1.5 m high and 6 m wide
 6.75 = Volume of one block

2. The dozer hours required to complete the construction are estimated using Eq 8. The volume determined above is adjusted by a factor of 1.59 to convert compacted volume to loose volume. The push distance

TIME NEEDED TO DETONATE CHARGE FOR ONE BLOCK

1.	Unload equipment at site	5 minutes
2.	Place one charge	15 minutes
3.	Check circuits, clear area, and fire	15 minutes
4.	Place 18 charges to cut rebars	18 minutes
5.	Check circuits, clear area, and fire	15 minutes
TOTAL		68 minutes

Figure 10

3. An explosive team of two people would expend 2.2 manhours of effort on one block. When more than one block is breached, the time increments are modified as shown in Figure 11.

TIME NEEDED TO DETONATE CHARGES FOR MORE THAN ONE BLOCK

1.	Unload equipment at site	7	Minutes
2.	Place charges	15 (X)	Minutes
3.	Check circuits, clear area, and fire	15	Minutes
4.	Place charges to cut rebars	18 (X)	Minutes
5.	Check circuits, clear area, and fire	15	Minutes
TOTAL		37+33 (X)	Minutes, where X = number of blocks

Figure 11

4. For every additional group of four blocks, an additional 6 minutes is added to account for the increased difficulty in reaching the target blocks. Also, for every group of four blocks, an additional two-man demolition team is added to the effort.

5. The estimate for loader effort (5 cubic yard) assumes that a loader used to clear rubble is half as effective as one used to

(a) Explosives. Explosives are used to break up the large blocks into more manageable rubble which can then be removed using loaders.

1. Counterforce charges were rejected as an alternative, since each block exceeds the 4 foot maximum width prescribed by FM 5-34. The side drops along the routes average 5 feet (1.5 m) thick. Although the use of internal charges to break up the blocks would require less explosive, the time expended would be half again as much for each block as that expended by placing external charges. FM 5-25, Figures 3-14, pp. 3-19, indicates that a breaching charge of 142 lb of TNT is required. To estimate the amount of C-4 explosive required, 142 is divided by the effectiveness factor for C-4 of 1.34. Then, 105.9 lb of C-4 is rounded up to 106 lb. Despite the external explosion, some of the rebars will require cutting before the rubble can be removed. Assume 18 rebars require cutting and that each rebar requires one pound of C-4. (This value is based on an initial 6x6 grid of rebars within the block.) The total amount of C-4 explosive required for one block is:

Breaching charge.....	106 lb
Rebar cutting charges.....	18 lb
TOTAL.....	124 lb

2. Figure 10 itemizes the time expended by an explosives team in preparing and detonating a breaching charge for one block. The team consists of one demolition specialist and one demolitions assistant. The time increments reflect a subjective estimate of requirements.


```

100 REM *****
110 REM *                MAIN MENU                *
120 REM *   This section is the primary menu for selecting the *
130 REM *   type of obstacle system for which calculations are *
140 REM *   desired.                                           *
150 REM * * * * *
160 PRINT '*Clear Screen*'
170 PRINT TAB(25):'MAIN MENU'
180 PRINT
190 PRINT 'This program will calculate and display the engineer effort'
200 PRINT 'required to overcome various obstacles to vehicular movement.'
210 PRINT 'Select the obstacle type that you wish to overcome and respond'
220 PRINT 'to the questions asked. All requested measurements are in'
230 PRINT 'metric units.'
240 PRINT
250 PRINT TAB(10):'(1) Tank/Drainage Ditch'
260 PRINT TAB(10):'(2) Berm/Levee'
270 PRINT TAB(10):'(3) Boulder/Concrete Obstacle Field'
280 PRINT TAB(10):'(4) Sidedrops (Using Explosives)'
290 PRINT TAB(10):'(5) Sidedrops (Using Earthmoving Equipment)'
300 PRINT TAB(10):'(6) QUIT'
310 PRINT
320 PRINT TAB(5):'INDICATE YOUR SELECTION, PLEASE: ':
330 INPUT A$
340 A=VAL(A$,1)
350 IF A<1 THEN GOTO 390
360 IF A>6 THEN GOTO 390
370 ON A GOSUB 1000,2000,3000,4000,5000,9999
380 GOTO 160
390 PRINT 'You must choose 1..2..3..4..5..or 6: ':
400 GOTO 330
1000 REM =====TANK/DRAINAGE DITCH=====
1010 PRINT '*Clear Screen*'
1020 REM -----
1030 PRINT 'The following program calculates the volume of earth required'
1040 PRINT 'to fill a ditch of given width and depth. The sides of the ditch'
1050 PRINT 'are reduced and the earth pushed into the ditch until the crossing'
1060 PRINT 'height of the ramp equals the height of the lip of the reduced'
1065 PRINT 'bank. Once the volume is determined, the number of dozer hours'
1067 PRINT 'required to accomplish the task are estimated.'
1070 REM -----
1080 REM The lane width is set at 3.5 meters. It may be changed at line 1100.
1090 REM -----
1100 W=3.5
1110 PRINT
1120 PRINT 'Enter the width of the ditch (meters): ':
1130 INPUT L
1140 PRINT 'Enter the depth of the ditch (meters): ':
1150 INPUT H

```

```

1160 LET X=0
1180 REM -----START LOOP-----
1190 X=X+.1
1200 IF X>H THEN 1290
1210 LET H1=H-X
1220 V1=(W*H1*L)+(H1*H1*L)
1230 V2=(10*W*X*X)+(6.66667*X*X*X)
1240 IF V2>V1 THEN 1310
1250 LET B=V1
1260 LET S=V2
1270 GOTO 1180
1280 REM -----END LOOP-----
1290 PRINT 'The algorithm is not working correctly. CHECK DATA.'
1300 GOTO 1410
1310 C=(B+S)/2
1320 PRINT 'Width','Depth','Volume','Dozer Hrs'
1330 PRINT L,H,C,C*(.5*L+5*H1)/6000
1340 PRINT
1350 REM -----
1360 REM   In this section of the program, commands peculiar to the
1370 REM   Basic software can be inserted to copy data to the
1380 REM   floppies and to print hard copies at the printer.
1410 REM -----
1420 PRINT 'Do you have another ditch calculation? ':
1430 INPUT Z$
1440 IF Z$='Y' THEN GOTO 1110
1450 RETURN
2000 REM =====BERM/LEVEE=====
2010 PRINT '*Clear Screen*'
2020 PRINT ' This subroutine calculates the volume of earth that must be'
2030 PRINT 'moved and the dozer hours necessary to construct a passage'
2040 PRINT 'for military vehicles through an earthen berm.'
2050 REM -----
2060 REM The lane width is set at 3.5 meters. It may be changed at line 2080
2070 REM -----
2080 W=3.5
2090 PRINT
2100 PRINT 'Enter the thickness of the berm (meters): ':
2110 INPUT L
2120 PRINT 'Enter the height of the berm (meters): ':
2130 INPUT H
2140 LET X=0
2150 REM -----START LOOP-----
2160 X=X+.1
2170 IF X>H THEN 2260
2180 LET H1=H-X
2190 V1=(W*H1*H1)+(.666667*H1*H1*H1)+(W*H1*L)+(L*H1*H1)
2200 V2=(2.747*W*X*X)+(6.66667*X*X*X)
2210 IF V2>V1 THEN 2280

```

```

2220 LET B=V1
2230 LET S=V2
2240 GOTO 2150
2250 REM -----END LOOP-----
2260 PRINT 'The algorithm is not working correctly. CHECK DATA.'
2270 GOTO 2370
2280 C=(B+S)/2
2290 PRINT 'Thickness','Height','Volume','Dozer Hrs'
2300 PRINT L,H,C,C*(.5*L+5*H1)/6000
2310 PRINT
2320 REM -----
2330 REM      In this section of the program, commands peculiar to the
2340 REM      Basic software can be inserted to copy data to the floppies
2350 REM      and to print hard copies at the printer.
2370 REM -----
2380 PRINT 'Do you have another berm/levee calculation? (Y/N): ':
2390 INPUT Z$
2400 IF Z$='Y' THEN GOTO 2100
2410 RETURN
3000 REM =====BOULDER/CONCRETE OBSTACLE FIELD=====
3010 PRINT '*Clear Screen*'
3020 PRINT ' This subroutine calculates the amount of time expended'
3030 PRINT 'by engineers to construct a passage through a field of'
3040 PRINT 'boulders or concrete obstacles.'
3050 REM -----
3060 REM Assume a checkerboard pattern of obstacles.....
3070 REM -----
3080 REM      Determine the number of boulders/row that must be removed.
3090 REM      If the width of each boulder plus the spacing on
3100 REM      each side is equal to or greater than 3.5 meters
3110 REM      than only one boulder is removed per row; otherwise,
3120 REM      two boulders per row are removed.
3130 REM =====
3135 PRINT
3140 PRINT 'Enter the spacing between boulders/obstacles: ':
3150 INPUT S
3160 PRINT 'Enter the width of each boulder/obstacle: ':
3170 INPUT W
3180 PRINT 'Enter the number of rows that must be crossed: ':
3190 INPUT R
3200 IF (2*S+W)<3.5 THEN N=2
3210 IF (2*S+W)>=3.5 THEN N=1
3220 REM -----
3230 REM      T1 = Time for Combat Engineer Vehicle
3240 REM      T2 = Time for dozers
3250 REM -----
3260 T1=(N*.0375+W*.0094)*R
3270 T2=(N*.3)*R
3280 PRINT 'Spacing','Width','Rows',' CEV',' Dozer'

```

```

3290 PRINT
3300 PRINT S,W,R,T1,T2
3310 REM -----
3320 REM      In this section of the program, commands peculiar to the
3330 REM      Basic software can be inserted to copy data to the floppies
3340 REM      and to print hard copies at the printer.
3350 REM -----
3360 PRINT 'Do you have another boulder field calculation? (Y/N): ':
3370 INPUT Z$
3380 IF Z$='Y' THEN GOTO 3140
3390 RETURN
4000 REM =====SIDEDROPS (EXPLOSIVES)=====
4010 PRINT '*Clear Screen*'
4020 PRINT '      This subroutine calculates the engineer effort'
4030 PRINT 'to overcome an obstacle made up of concrete blocks'
4040 PRINT 'which have been dropped into the roadway. The method'
4050 PRINT 'used is to place one explosive charge per block and'
4060 PRINT 'to remove the resulting debris with a loader.'
4070 PRINT
4080 PRINT 'How many blocks have been dropped into the road?: ':
4090 INPUT N
4100 REM -----
4110 REM The amount of explosives needed equals 124 lbs per block
4120 REM -----
4130 E=N*124
4140 REM -----
4150 REM The time required to remove the rubble with a loader is
4160 REM      calculated first
4170 REM -----
4180 R=(2*N*6.75)/(300*.765)
4190 REM -----
4200 REM Now, the total time is calculated by adding the time needed
4210 REM      to set and detonate the explosives to the loader time
4220 REM -----
4230 IF N>4 THEN GOTO 4260
4240 T=R+(37+33*N)/60
4250 GOTO 4270
4260 T=R+(169+6*(N/4-1))/60
4270 REM -----
4280 REM The crew size is calculated - For every four blocks two
4285 REM      additional engineers are added to the work crew.
4290 REM -----
4300 IF N>4 THEN GOTO 4330
4310 C=3
4320 GOTO 4340
4330 C=3+2*INT(N/4)
4340 REM -----
4350 REM Print out the results: # of blocks, lbs of explosives,
4360 REM      crew size, and time expended at the site

```

```

4370 REM -----
4380 PRINT ' # of',' lbs of','crew','Total'
4390 PRINT 'blocks','explosives','size','Time'
4400 PRINT N,E,C,T
4410 PRINT
4420 PRINT 'Do you have another sidedrop calculation? (Y/N): ':
4430 INPUT Z$
4440 IF Z$='Y' THEN GOTO 4080
4450 RETURN
5000 REM =====SIDEDROPS (USING EARTHMOVING EQUIPMENT)=====
5010 PRINT '*Clear Screen*'
5020 PRINT 'This program calculates the amount of earth and dozer hours'
5030 PRINT 'required to fill in a cut which has been blocked by a specific'
5040 PRINT 'number of concrete sidedrops. The dimensions of each sidedrop'
5050 PRINT 'are assumed to be 3x1.5x1.5 meters.'
5060 PRINT
5070 PRINT 'The data required are: The number of blocks along the road.'
5080 PRINT '                               The length of the blocked section of'
5090 PRINT '                               road from the beginning of the first'
5100 PRINT '                               block to the end of the last.'
5110 PRINT
5120 PRINT 'How many blocks make up the obstacle?: ':
5130 INPUT N
5140 PRINT 'How long is the obstacle (meters)?: ':
5150 INPUT L
5160 REM -----
5170 REM This portion calculates the volume of earth required by calculating
5180 REM the volume of the cut then subtracting the volume of the blocks.
5190 REM -----
5200 REM 1. Volume of two center wedges:
5210  $V1=4*1.5*15$ 
5220 REM 2. Volume of four pyramids:
5230  $V2=2/3*1.5*1.5*15$ 
5240 REM 3. Volume of the center parallelopiped:
5250  $V3=4*1.5*L$ 
5260 REM 4. Volume of two prisms:
5270  $V4=1.5*1.5*L$ 
5280 REM 5. Volume of the concrete blocks:
5290  $V5=N*(1.5*1.5*3)$ 
5300 REM 6. Total Volume:
5310  $V=V1+V2+V3+V4-V5$ 
5320 REM
5330 REM The amount of loose earth required to fill this volume is
5340 REM estimated by using a conversion factor of 1.59 (from FM 5-34,
5350 REM page 299).
5360  $V=V*1.59$ 
5370 REM The number of dozer hours required:
5380  $D=V*L*2/6000$ 
5390 PRINT

```

```
5400 PRINT ' Road','Number of','','Dozer'
5410 PRINT 'Length','Obstacles','Volume','Hours'
5420 PRINT L,N,V,D
5430 PRINT
5440 PRINT 'Do you wish to calculate another sidedrop? (Y/N): ':
5450 INPUT Z$
5460 IF Z$='Y' THEN GOTO 5110
5470 RETURN
9999 END
```

LAST PAGE OF ANNEX

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