ROAD CAPABILITY STUDY ON IMPROVED EARTH ROADS

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•DURING the past several years, personnel from the U.S. Department of Defense, civilian agencies, and highway agencies concluded that opinions differed on estimating methods of road capacity. A research analysis program was, therefore, conducted for refining factors for assessing road capability.

Field tests in the continental United States (CONUS) involved operating as many as 10 two-axle resupply vehicles in convoy on closed single-lane loops on a 24-hour basis for several consecutive days. Tests were conducted on improved earth roads with surface soils composed of silty sand (SM), lean clay (CL), and fat clay (CH) at dry, moist, and wet conditions. The tests on silty sand and lean clay were conducted during May 1971, and tests on fat clay were conducted during September 1971.

The field tests in Southeast Asia (SEA) involved monitoring operational convoy moves as well as conducting controlled tests on lateritic soils. These tests were conducted in accordance with the same test plan that was used in the CONUS test programs.

TEST SITES

Tests on silty sand and lean clay roads were conducted at Camp Wallace, Virginia, located on the James River. The terrain consists of rugged woodland with heavy growths of underbrush and is representative of mountainous terrain where there are improved earth roads. Because no fat clay was found at a suitable location in Virginia, arrangements were made with the U.S. Army Corps of Engineers to conduct tests on a fat clay road near Vicksburg, Mississippi. Relevant data on soils of volcanic origin in tropical areas of the world (lateritic soils) were obtained in tests conducted in the Long Binh area of the Republic of Vietnam. Typical views of these test sites are shown in Figure 1. The detailed characteristics of all the test roads, which were closed loops with 1-way traffic only, are given in Table 1.

TEST VEHICLES

It was desired that the test vehicle simulate 2-axle resupply truck with a gross weight of 16,260 lb, rear-axle drive only. This was accomplished in the Virginia test by using M35A2 trucks with the intermediate-axle wheels removed and the drive shaft to the front axle disconnected. Twenty M35A2 trucks were temporarily modified and driven in the tests. The Mississippi tests were conducted with commercial 2-axle flatbed trucks because these were readily available and required no modifications to meet the requirements for test truck characteristics. The test vehicles used in the Long Binh tests were commercial 2-axle dump trucks with flatbeds.

TEST PROCEDURES

All of the test courses were in the form of closed loops with single-lane traffic in 1 direction. The test vehicles were run on a 24-hour basis. In the CONUS tests, there were three 8-hour shifts; and in the SEA tests, there were two 12-hour shifts. Approximately 6.5 hours were lost during a 24-hour period because of required stops for rest, meals, and vehicle maintenance.

During each test period, the vehicles were driven at maximum speeds, consistent with safe driving conditions. Several times during each shift a check was made of the

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average speed around a given test loop, and also an instantaneous check was made of the average vehicle lead and speed of the lead and rear vehicles in the convoy.

Road maintenance equipment at each test site in CONUS consisted of a motor grader, a bulldozer, and a water distributor. Practically all road maintenance was accomplished by use of the motor grader. The bulldozer was used only to muck out the low soft spots that slowed the operations following any rains. Maintenance was performed when rutting exceeded 6 to 8 in., washboarding occurred, or potholes caused driving to become more difficult and speed to be reduced. This was accomplished during meal and vehicle stops and during short periods when road capability could be substantially increased. Road maintenance was kept to a minimum throughout the entire test periods. Time and type of equipment used to perform road maintenance were recorded in the test data records.

There was no road maintenance performed on the SEA test loop because the surface soils were more stable inasmuch as they contained ferrous oxides and deteriorated at a slower rate than the CONUS soils. Operations were sustained when vehicles straddled ruts in the small sections of road that had failed. As these ruts progressively worsened, the speeds of vehicles were reduced, but a substantial volume of traffic could be maintained. Adequate road maintenance equipment was available on site, but the tests concerned keeping operations as close to actual enemy combat conditions as possible.

Soil borings for classification in accordance with the United Soil Classification System were taken in all test loops in order to identify the soil types in the test loops and at critical points. All soil tests and laboratory analyses were conducted in accordance with the current test procedures of the U.S. Army Corps of Engineers. Frequent moisture, density, and cone penetrometer readings were taken before, during, and after all test periods to document the test conditions under which each test was performed.

DETERMINATION OF ROAD CAPABILITY

Road conditions that affect road capability include factors such as vertical and horizontal alignment, surface type and width, visibility, and roadway maintenance. Traffic conditions, consisting of factors that influence vehicle movements and those that are generated by all vehicles using the road, include crossing and turning movements, movements of additional vehicles not normally associated with supply movements, interference caused by opposing vehicular movement, and diversity in sizes of vehicles composing the traffic stream. Certain factors that are normally of major importance in estimates of the capacity of an uncontrolled high-density roadway are not applicable to controlled supply movements. More rigid control is normally exercised in supply movements than in movements of freely moving civilian passenger vehicles. Despite this control, there will be some variation in vehicle spacing and speed, owing largely to the influence of roadway alignments. To develop an accurate capacity estimate for supply vehicle movements requires that all factors pertaining to the type of roadway under consideration be weighed in proper perspective. The factors cannot be established as exact figures but are to be judiciously applied in accordance with related conditions.

The results in this test program are based on a strictly controlled, 1-way supply movement where there was no other traffic permitted on the supply route and where vehicle lights were on during night operations. Many of the factors that affect capability were built in the selected test loops. Factors such as vertical and horizontal alignment, width, and surface type are constants for a given test loop and can be related to a type of improved earth road supply route. Factors that are variables include moisture condition of the surface soil, road maintenance, vehicle speed and lead, driver behavior and experience, and fixed time loss (10-min rest stops). Because maximum road capability is significant in supply movements, the maximum speed and the minimum lead consistent with safe driving conditions were striven for. Test road characteristics, speed and lead, vehicle rates, road maintenance data, and computed road capacities are given in Table 2.



Table 1. Test loop characteristics.

Location	Test Loop	Soil Type [*]	Length (ft)	Avg Width (ft)	Maximum Width (ft)	Minimum Width (ft)	Maximum Grade (percent)	Minimum Radius Curve (ft)
Virginia	1 2 3	SM CL, SM, SC SM	2,420 4,700 3,717	20.2 19.0 40.0	24.0 39.0 40.0	16.5 12.1 40.0	10 to 7 8 and 20 1.5	61 48 240
Mississippi	1	CH	2,670	18.0	18.0	18.0	12.0	75
Long Binh	1	SC, SM, SP, SW, CL, CH	3,070	20.1	38.0	18.3	9.0	202

*United Soil Classification System, where CL = lean clay, CH = fat clay, SC = clayey sands, SM = silty sands, SP = poorly graded sands or gravelly sands, and SW = well-graded sands or gravelly sands.

Table 2. Road capabilities.

Location	Soil Type	Soil Condi- tion	Avg Width (ft)	Maximum Grade (percent)	Mini- mum Radius Curve (ft)	Avg Lead ^a (ft)	Avg Speed ^a (mph)	R	C.	М	Pv
Virginia	CL, SC, SM	Dry	19.0	8 and 20	48	207.0	15.8	402.0	1,337	11.2	1,600
Virginia	CL, SC, SM	Moist	19.0	8 and 20	48	171.1	14.1	433.0	1,337	11.2	1,630
Virginia	CL	Wet	19.0	8 and 20	48	0.0	0.0	0.0	0	0.0	0
Virginia	SM	Moist	20.2	10 and 7	61	111.8	18.8	888.0	1,573	8.1	2,780
Virginia	SM	Wet	20.2	10 and 7	61	147.1	20.5	735.0	1,021	10.9	1,450
Virginia	SM	Moist	40.0	1.5	240	134.0	27.8	1,100.0	3,414	14.2	3,440
Virginia	SM	Wet	40.0	1.5	240	140.5	21.6	809.0	2,104	5.7	4,410
Mississippi	CH	Dry	18.0	12.0	75	89.0	21.0	1,240.0	1,032	5.2	2,980
Mississippi	CH	Moist	18.0	12.0	75	101.0	20.0	1,040.0	724	12.2	976
Mississippi	CH	Wet	18.0	12.0	75	0.0	0.0	0.0	0	0.0	0
Long Binh	SM, SW, SP,										
	SC	Wet	20.1	9.0	202	429.0	2.9	24.6	NA	0.0	366°
Long Binh	CL, CH	Wet	20.1	9.0	202	0.0	0.0	0.0	0	0.0	0°
Long Binh	SM, SW, SP,										
	SC, CL, CH	Moist	20.1	9.0	202	179.0	19.8	584.0	NA	0.0 ^b	8,687°
Long Binh	SM, SW, SP,										
	SC, CL, CH	Dry	20.1	9.0	202	145.0	22.2	809.0	NA	0.0 ^b	12,034°

^aBased on numerous tests throughout 24-hour periods.

^bNo road maintenance was required on lateritic soils due to slow rate of deterioration versus CONUS soils,

 ${}^{c}P_{v} = f(24 \cdot L_{1})R$ when no maintenance is accomplished as in SEA,

The equation for computing road capacity is as follows:

$$\mathbf{P}_{v} = \mathbf{f} \ \mathbf{C}_{\mathtt{s}} \left\{ \frac{(24 - \mathbf{L}_{t})}{\left\lfloor (\mathbf{C}_{\mathtt{s}}/\mathbf{R}) + \mathbf{M} \right\rfloor} \right\} \text{ when } \left\lfloor (\mathbf{C}_{\mathtt{s}}/\mathbf{R}) + \mathbf{M} \right\rfloor \leq (24 - \mathbf{L}_{t})$$

where

- P_{v} = vehicle passes/24-hour period;
- f = reduction factor (0.85) to compensate for contingencies such as egress and ingress of vehicles;
- C_n = number of vehicle passes before road maintenance is required;
- R = theoretical number of vehicles per hour that can pass a fixed point in 1 direction (5.280 × avg speed/avg lead);
- M = time loss due to road maintenance/fixed number of passes; and
- L_t = fixed time loss due to rest stops (10-min stops), 3.5 for CONUS and 6.5 for SEA.

The term $[(C_n/R) + M]$ represents 1 road maintenance cycle. That is the total time for C_n vehicles moving at a rate of R per hour to pass plus the time required to repair the road. The term $(24 - L_t)$ fixes the amount of time available in a 24-hour day. Division of the available time by the road maintenance cycle time gives the number of cycles that can be accomplished in one 24-hour day; multiplying this by the number of vehicle passes per cycle and modifying the result by f give the maximum road capacity. The data given in the last column of Table 2 are considered to be realistic maximums for the road characteristics given in the table.

The vehicle maintenance records for the tests indicate that 2 vehicles would be required to keep 1 operation in a continuous short-haul resupply operation over the same short closed-loop route. A large maintenance float would be required to sustain this type of operation because the vehicles would take continuous pounding on the same mechanical components. On a long-haul convoy operation this would not be prevalent. Some maintenance support would be necessary but not to the extent as required in the closed-loop operation. In addition to the maintenance float required, adequate road maintenance equipment must also be available. The test records indicate that the equivalent of 1 motor grader per 4 miles of road is needed for minimum road maintenance. It was also noted that road maintenance was not necessary if one is willing to reduce vehicle capacity gradually based on percentage of the road that has deteriorated. Thus, the analysis of the test records clearly indicates that to sustain the maximum road capacity requires adequate maintenance float vehicles and road maintenance equipment.

This analysis indicates that the ability of a given country to sustain a large resupply operation is dependent not only on the type of roads available but also on the supply of vehicles and ability to keep them operational. Under wet conditions the road would be the controlling factor.

TYPICAL SOIL FAILURES IN THE ROAD SURFACE

The types of failures that require road maintenance to improve capacity, to reduce hazardous driving conditions, or to minimize mechanical damage to the vehicles (or all of these) are discussed below under the various soil types.

Silty Sand

Figure 2 shows the situation that existed after a dry test with 1,320 vehicle passes, i.e., on a curve to the left, downgrade, potholes to 10 in. deep, and fine powdery soil piled along the outside of the curve 18 to 24 in. high.

Figure 3 shows a straight, level, poorly drained, highly consolidated silty sand where there is a deep pothole near the center. It was necessary to muck out this section of road several times after rains (note pile of soil in the left of photograph); however, the vehicles were never immobilized here. This situation existed after a moist test.

On a level, slightly banked curve to the right, severe washboarding occurred after 1,573 vehicle passes (Fig. 4). (Note piles of soil near the top of photograph.)

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Figure 2. Potholes in Virginia road.



Figure 4. Washboarding in Virginia road.



Figure 3. Poorly drained section in Virginia road.



Figure 5. Deep depressions in Virginia road.



Figure 6. Deep rutting in Virginia road.



Figure 8. Deep depressions and potholes in Mississippi road.



Figure 10. Deep depression, washboarding, and soil buildup in SEA road.



Figure 7. Deep potholes in Mississippi road.



Figure 9. Deep rutting and deterioration in SEA road.



Figure 11. Dust along SEA road.



Figure 5 shows a failure that occurred at the bottom of a downhill grade on a slight curve to the right. This section of road was constructed on a low fill. Note the deep depressions in the left wheel track after 1,320 vehicle passes.

Deep rutting occurred at this location on a sharp curve to the left at the bottom of an uphill grade after moist tests (Fig. 6). Although the undercarriage of the vehicles often touched the center of the road surface, no vehicles were immobilized here during the moist tests. The vehicles were immobilized here during a wet test because of slipper-iness, not sinkage.

Fat Clay

Deep potholes developed at this location on a downhill grade and curve to right as a result of a dry test. Traffic moved to the left, as shown in Figure 7.

Deep depressions and potholes developed at the bottom of an uphill grade and a curve to the right as a result of a moist test (Fig. 8).

Lateritic Soils

Deep rutting and complete deterioration of surface at this location of CL-CH soil on an uphillgrade, and a curve to the left developed as a result of a wet test. Vehicles were immobilized during monsoon. Traffic moved to the right, as shown in Figure 9.

Deep depressions, washboarding, and buildup of soil to the right on an uphill grade and a curve to the right developed as a result of moist test (Fig. 10).

On a downhill grade, slightly curving to the right, dusty condition, rutting, and buildup of soil to the left of road occurred as a result of dry test (Fig. 11).

CONCLUSIONS

1. Roads in CONUS composed of silty sands, lean clay, or fat clay in the dry or moist condition, compacted to 90 to 100 percent of maximum density, and maintained at periodic intervals can support the passage of a thousand or more vehicles of the 2-axle type in a 24-hour period.

2. Roads in SEA composed as indicated above and having the same conditions were able to achieve and sustain maximum density without any road maintenance because of the high humidity, which provides moisture, and the ferrous oxides in laterites, which reacted as soil stabilizers. The traffic provided the necessary compactive effort.

3. Roads in CONUS composed of silty sands in the wet condition, compacted to 90 to 100 percent of maximum density, and maintained at periodic intervals can support the passage of a thousand or more vehicles of the 2-axle type in a 24-hour period.

4. Roads in SEA composed of silty sand in the wet condition, compacted to 90 to 100 percent of maximum density, and not maintained can support the passage of several hundred vehicles of the 2-axle type in a 24-hour period.

5. Roads in CONUS and SEA composed of lean clay or fat clay in the wet condition and having uphill grades of approximately 6 and 8 percent or more respectively will immobilize vehicles of the 2-axle type because of slipperiness. On roads with grades less than approximately 6 percent, some traffic can travel at very low speeds provided penetration of surface moisture has not exceeded more than approximately 3 in.

6. Vegetation that provides a canopy over a road prolongs moisture retention in the road surface soil after rains. This condition will have a significant effect on road usage.

7. Assuming that a given improved earth road is in a trafficable condition, a large maintenance float and adequate road maintenance will be required to support volume movements of vehicles because of the effects of dust, road roughness, frequent shifting of gears, and frequent braking actions that cause rapid mechanical failures such as fractured radiator connections and mountings, failure of wheel axle seals and brake lines, and clutch component failures. This will be prevalent for short-haul, closed-loop operations but reduced for long-haul operations.

8. The ability of a given country to mount and support maximum resupply movements over improved earth roads is not dependent on the roads available but on the number and quality of resupply vehicles and the ability to maintain the vehicles and road.