DETERMINING HIGHWAY SHOCK INDEX

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The U.S. Army, Navy, Air Force, and Marine Corps have jointly sponsored and participated in the development of a shock index for highway transportation. A numerical shock index, associated with a particular vehicle-load combination, can now be determined at a low cost by applying simple static field measurements. The shock index provides classification for a vehicle-load combination in regard to probability of shocks transmitted to the cargo during highway shipments.

•IN 1967, representatives of the U.S. Army, Navy, Air Force, and Marine Corps agreed that it should be possible to establish shock indexes that would be representative of the cargo environment for various transport modes. Together, the services formed a steering committee to initiate and guide the development of a highway shock index (SI). The highway mode was selected because of the relative ease in controlling the environment and related variables.

As an initial step, the steering and advisory committee let a \$53,000 contract to General Testing, Inc., Springfield, Virginia, to determine and develop an SI equation that could be used to classify highway cargo vehicles in terms of vehicle shock to the cargo. In addition and in conjunction with the General Testing contract, a \$13,000 contract was let to J. A. Johnson, Inc., Short Hills, New Jersey, to check and verify the General Testing, Inc., project objective. General Testing ran comprehensive static and dynamic shock evaluation tests by using five classes of cargo trucks.

General Testing mostly performed controlled laboratory tests. J. A. Johnson was to validate the feasibility of the General Testing classification procedure and to test it on public roads to establish the accuracy of method on the road. From this check, it was concluded that an SI classification is both feasible and needed by the military community but that more engineering expertise is required to improve accuracy before the classification procedure can be adopted.

Accordingly, the Military Traffic Management Command Transportation Engineering Agency (MTMCTEA) initiated a comprehensive SI field test program using Fort Eustis facilities, military equipment, and personnel to develop a practical test for obtaining usable impact data. A military 5-ton (4.5-Mg) M52 tandem tractor with a 12-ton (10.8-Mg) M127 tandem trailer was used for this phase of the test program. Using military personnel and equipment considerably reduced research costs and ensured technical control of the field work. As a result of these tests, a procedure for testing commercial cargo trucks was developed.

During July 1973, limited field tests were initiated on the first of three leased commercial cargo trucks; all field work was completed by April 1974. Support for these tests was provided by the U.S. Army Transportation Center and Fort Eustis. MTMCTEA engineers performed the planning, supervision of tests, analyses, and development of concepts and their application.

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PURPOSE OF SHOCK INDEX

The purpose of the highway SI is to provide a means for selecting highway cargo vehicles on the basis of their rough riding characteristics. The selection is not based on the vehicle configuration but on the combined payload spring rate K of the springs and tires on an axle. SI makes it possible to select a relatively soft riding vehicle for fragile cargo and thus to minimize the possibility of damage to the cargo. The SI rating system applies to restrained cargo only.

The SI for a cargo vehicle should be representative of the roughest ride area on the truck cargo bed. Previous tests have shown and recent tests have confirmed that, under normal operating conditions, for a two-axle cargo truck, the roughest ride on a truck cargo bed is found over the rear axle or, for a truck-tractor semitrailer combination, it is found either near the rear axle of the trailer or over the fifth wheel of the truck-tractor, depending on which axle has the higher payload spring rate.

Under normal operating conditions, maximum shocks on the cargo bed will occur in the vertical direction. Based on extensive tests by MTMCTEA and other organizations, a maximum shock of $10g$ is considered reasonable for a very rough road surface. Consequently, the highway SI is based on a scale of 0 to 10g. The numerical values of SI vary from 5 to 0; 5 corresponds to 0g, and represents the softest ride.

The deadweight of the vehicle is not involved in the determination of SI; the unloaded weight of the vehicle is already in place and, therefore, is not involved in the determination of the payload spring rate. The tests have shown that of the three major variables, percentage of maximum payload, tire pressure, and speed, percentage of maximum payload has a major effect on SI, whereas tire pressure in the practical range and speed causes relatively minor changes.

Since percentage of maximum payload has the most effect on the ride on the truck cargo bed, a graph relating the payload axle spring rate, axle payload, and SI was developed (Figure 1). To develop Figure 1, tests were conducted on a range of cargo vehicles. The payload capability of these vehicles varied from 13,000 lb (5900 kg) on a two-axle truck to 24,000 lb (10 900 kg) on a two-axle truck-tractor, single-axle trailer combination to 40,000 lb (18 140 kg) on a three-axle truck-tractor, two-axle semitrailer combination.

The vehicles were instrumented to measure shock on the cargo bed and were driven over fixed, unyielding bumps at various speeds at different tire pressures and with different payloads.

The repeatability of data measurements recorded on the test course was satisfactory in spite of the many variables that affect a dynamic test of this type. Approximately 80 percent of all data recorded over the axles of the trucks was used for Figure 1 and Table 1.

SHOCK INDEX GRAPH

Based on the SI graph (Figure 1), several conclusions can be made. As axle payload increased from zero, the shock index increased to some optimum load for the vehicle and, thus, provided a softer ride. The dashed lines on Figure 1 indicate a trend reversal in which increasing the axle payload causes a decrease in shock index and, thus, provides a progressively rougher ride. There is an optimum payload for all vehicles that will provide the softest ride for the cargo. This optimum load can be readily selected from Figure 1 when the combined axle payload spring rates for the vehicle are known.

High, erratic shock values are most likely to occur with very light or maximum payloads because when the loads are light, the vehicle springs are relatively stiff and when the loads are very heavy, bottoming out of the springs may occur. The most erratic results will occur over the fifth wheel area because of the concentration of load at the kingpin.

Figure 1 shows that for a relatively soft ride the vehicle payload axle spring rate should be about 7,000 lb/in. (1250 kg/cm). For an axle payload of 3,000 lb (1360 kg),

Figure 1. Payload axle spring rate versus shock index.

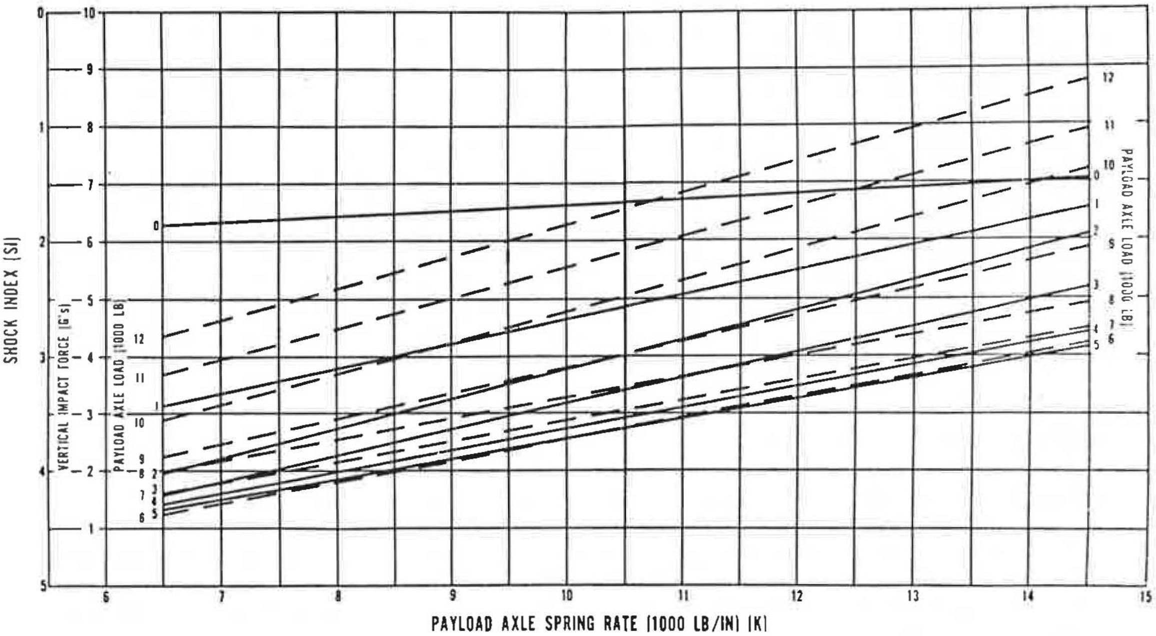

Figure 2. Rear view of truck.

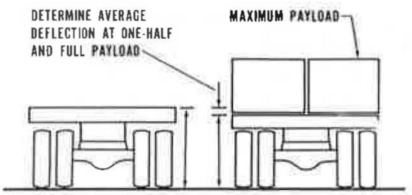

Figure 3. Axle payloads.

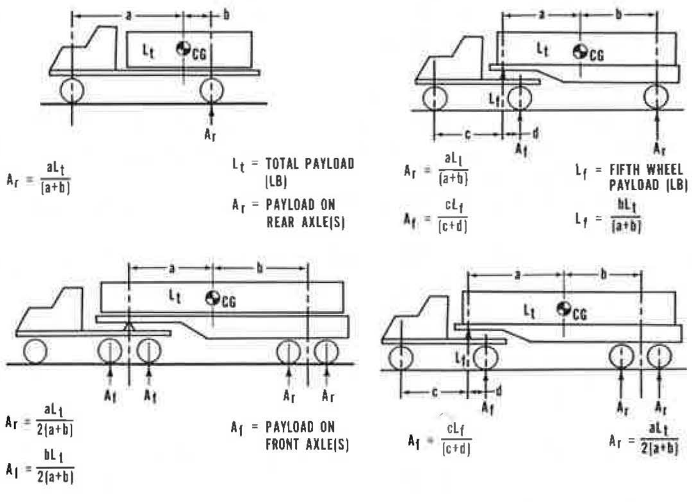

Table 1. Shock index values.

Payload Axle Load (lb)	Payload Axle Spring Rate (lb/in.)																
	6,500	7,000	7,500	8,000	8,500	9,000	9,500	10,000	10,500	11,000	11,500	12,000	12,500	13,000	13,500	14,000	14,500
0	1.85	1.85	1.80	1.80	1.75	1.75	1.70	1.70	1.65	1.65	1.60	1.60	1.55	1.55	1.50	1.50	1.45
1,000	3.40	3.30	3.20	3.10	3.00	2.90	2.75	2.65	2.55	2.45	2.35	2.25	2.15	2.05	1.95	1.80	1.70
2,000	4.00	3.85	3.75	3.60	3.50	3.35	3.20	3.10	2.95	2.85	2.70	2.60	2.45	2.35	2.25	2.10	1.95
3,000	4.20	4.05	3.95	3.85	3.75	3.60	3.50	3.40	3.30	3.15	3.05	2.95	2.85	2.70	2.60	2.50	2.40
4,000	4.25	4.15	4.05	3.95	3.90	3.80	3.70	3.50	3.50	3.40	3.35	3.25	3.15	3.05	2.95	2.85	2.75
5,000	4.30	4.20	4.10	4.05	3.95	3.85	3.75	3.70	3.60	3.55	3.45	3.35	3.25	3.15	3.10	3.00	2.90
6,000	4.35	4.25	4.15	4.05	3.95	3.85	3.75	3.70	3.60	3.50	3.40	3.30	3.25	3.15	3.05	2.95	2.85
7,000	4.15	4.05	3.95	3.90	3.80	3.70	3.65	3.55	3.45	3.35	3.30	3.20	3.10	3.00	2.90	2.85	2.75
8,000	4.00	3.90	3.80	3.70	3.60	3.55	3.45	3.35	3.25	3.15	3.05	2.95	2.90	2.80	2.70	2.10	2.00
9,000	3.90	3.75	3.65	3.55	3.40	3.30	3.20	3.10	2.95	2.85	2.75	2.60	2.50	2.40	2.30	2.15	1.95
10,000	3.55	3.40	3.25	3.10	3.00	2.85	2.75	2.60	2.45	2.30	2.20	2.05	1.90	1.80	1.65	1.50	1.40
11,000	3.15	3.00	2.90	2.75	2.60	2.50	2.35	2.25	2.10	2.05	1.85	1.70	1.55	1.45	1.30	1.15	1.05
12,000	2.80	2.65	2.55	2.40	2.25	2.10	2.00	1.85	1.70	1.60	1.45	1.30	1.20	1.05	0.90	0.75	0.65

Note: 1 lb/in. = 0.178 kg/cm. 1 lb = 0.45 kg.

the cargo would most likely not be subjected to a shock of over 2g, and the SI rating for the vehicle would be about 4.1.

For a vehicle payload axle spring rate of 10,000 lb/in. (1790 kg/cm), the maximum expected shock to the cargo should not exceed about 4g for axle payloads of 3,000 to 9,000 lb (1360 to 4080 kg). This vehicle would have an SI of about 3.

For a vehicle payload axle spring rate of 13,000 lb/in. (2320 kg/cm), the maximum expected shock to the cargo should not exceed about 6g for axle payloads of 3,000 to 9,000 lb (1360 to 4080 kg). This vehicle would have an SI of about 2.4.

For all ranges of payload, because of the many variables, dynamic behavior, and variable environment associated with the vehicle-road relationship, some radical inexplicable shock values will occur. In the test leading to the development of Figure 1, about 20 percent of the recorded values were inexplicable and were accordingly discarded.

DETERMINING SHOCK INDEX

The procedure for estimating SI for a specific cargo truck involves two steps.

1. The truck must be loaded and unloaded, and measurements of how much the cargo bed deflects under one-half and full payload must be taken.
2. The payload axle load must be known; this can be determined on a set of portable scales or by calculation.

This information must be obtained by physical measurements because of the high variable internal friction in leaf springs, variable stiffness in tire sidewalls, and general construction of the overall suspension system of the vehicle. Correlation between the manufacturer's spring rate for a leaf spring of a vehicle cannot be made with the installed spring because, in the manufacturer's test procedure, the test is performed without center clamps and shackles and the spring ends are mounted on rollers so that they are free to move (1). When the SI for a specific make and model of truck has been determined, it should apply to others of the same make and model with the same type of springs and tires.

The following information is required so that SI can be determined:

1. Vertical deflection at one-half and full payload of the truck bed at rear axles or at rear axles of truck-tractor for truck-tractor, semitrailer combination and
2. Payload axle load causing the vertical deflections.

The following procedures are used to determine combined (springs and tires) vertical deflection at axles:

1. Check tire air pressure, and adjust to operating pressure.
2. Position axles on scales, or, if scales not available, on a uniformly smooth, level, unyielding surface and then unload vehicle.
3. Accurately measure the height of the cargo bed on each side of the truck at the axles. If the vehicle is on scales, note unloaded load of axles.
4. Use dummy concentrated weights, if available, to simulate axle payload. Load with center of gravity directly over axle for single-axle vehicles or midway between tandem axles. If concentrated weights are not available, use available homogeneous weights and uniformly load truck bed. Accurately measure the height of the cargo bed on each side of the truck at the axles (Figure 2).

The truck should be loaded and unloaded several times, and an average deflection should be accurately determined at one-half and full payload by the method below:

1. Place full load on the truck and measure the truck bed height,
2. Unload to one-half full load and measure the truck bed height,

3. Unload truck and measure the truck bed height,
4. Place one-half full load on the truck and measure the truck bed height,
5. Place full load on truck and measure the truck bed height, and
6. Repeat above cycle 5 times for 10 measurements.

Accuracy of measurements should be within $\frac{1}{32}$ in. (0.8 mm).

Payload per axle at one-half and full payload is then determined: (a) If vehicle is on scales, read recorded weight, subtract axles unloaded weight, and, if there are tandem axles, divide by 2 and (b) if scales are not available, use one of the equations in Figure 3 to determine the single-axle payload at one-half and full payload.

The combined payload spring rate K for axles is then determined:

$$K = \frac{\text{full payload axle load in lb - one-half payload axle load in lb}}{\text{average deflection at full payload in in. - average deflection at one-half payload in in.}}$$

Now that K has been determined for the axles, the SI can be read directly from Figure 1 or Table 1. The most accurate reading can be obtained by using Figure 1 since a table must be based on some arbitrary interval of K. An interval of 500 lb/in. (89 kg/cm) is used for Table 1.

To use Figure 1, enter K on horizontal scale, read vertically to axle payload for trip, and read horizontally for SI. SI for each axle should be checked, and the lower numerical values should be used for the SI. This will represent the roughest expected ride on the cargo bed. The SI can be obtained, at the same time, for all axle payloads from 0 to 12,000 lb (5443 kg). It need be determined only once for vehicles of the same make and model with the same type springs and tires.

To use Table 1, use the K in the table that most nearly corresponds numerically to the K determined by physical measurement. The maximum error in SI due to using the table will be 0.625; in most cases, the error will be considerably less. The SI for each axle (if the vehicle is a truck-tractor, semitrailer combination) should be checked, and the lower numerical values should be used for SI.

For example, determine the SI for a two-axle truck-tractor, single-axle semitrailer combination. Payload axle loads for the rear axle of the tractor and the trailer axle are to be 10,000 lb (4536 kg) each.

The truck was loaded to one-half and full payload, and deflections were measured. Scales were used to determine the payload axle load on each axle. The following data were obtained on the trailer axle: 12,288 lb (5573.7 kg) for full payload axle load, 6,123 lb (2777.3 kg) for one-half payload axle load, 1.127 in. (2.85 cm) for average deflection at full payload, 0.687 in. (1.73 cm) for average deflection at one-half payload, and

$$K = \frac{12{,}288\ \text{lb} - 6{,}123\ \text{lb}}{1.127\ \text{in.} - 0.687\ \text{in.}} = 14{,}000\ \text{lb/in.}\ (2497\ \text{kg/cm})$$

Enter K on Figure 1, read vertically to the payload axle load that the truck is to transport [10,000 lb (4536 kg)], and read horizontally to SI. For K = 14,000 lb/in. (2497 kg/cm) and for payload axle load = 10,000 lb (4536 kg), SI = 1.52. SI from Table 1 is 1.50.

This procedure should also be used on the rear axle of the truck-tractor and 1.50 should be used as the SI for the truck with 10,000-lb (4536-kg) payload axle loads. The SI for all other payload axle loads can be determined directly from the graph or table by using the value of K for the truck, since K is independent of the payload.

CONCLUSIONS

The research (2) developed a set of semiempirical relationships to equate the performance of the vehicle and the cargo with the significant variables affecting the ride. The findings of General Testing, Inc., are not the ultimate answer to the problem of cargo ride but can be used to build a firm set of requirements for the safe transportation of all cargo.

REFERENCES

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