SHOCK INDEX CLASSIFICATION FOR HIGHWAY VEHICLES

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A program, jointly sponsored and promoted by the Army, Navy, Air Force, and Marine Corps, has produced a shock index classification for highway vehicles. The index is an empirical relation among the static mechanical characteristics of the vehicle and the low frequency shocks transmitted to the cargo. It is relatively simple and intended to be a user guide for shock transmitted to the cargo during transportation. This paper gives the formulas and methodology for obtaining the index. The first planned use is for traffic managers to effect a rough balance in service between the vehicle cushioning and cargo fragility. Cargoes whose loss costs are small compared to added vehicle-cushioning costs will also be balanced for optimum economics when the index ratings are known. A comprehensive program will extend the same concept to all modes. Also shock indexes or similar empirical factors will be developed for classifying highway pavements with regard to shocks transmitted by various highway pavements.

•MODERN shipment of cargo by intermodal containers has forced transportation personnel for all modes to know more about damage-producing shocks and vibrations and to become better organized to control them. Improvements or classifications are required across the board for total system improvement. There is an absence of definitive information regarding damage-causing shocks transmitted to cargo during transit. Loss and damage are not known to be significantly higher for highway shipments than for shipments by other modes of transportation. Perhaps this is the reason why more effort has not been expended to study, analyze, and control highway shocks.

Three principal areas of utilization compel the military to pursue control of highway shocks. The first is that highway transport for connector hauls and to terminals and ports for transshipment is extensive. The second is the high priority for improving the shock attenuation to shipments of hazardous, fragile, and key items or military materiel. The third is the increase in intermodal containerized shipments.

There has been a marked increase in the number of military cargoes where better than average ride for highway shipping would substantially improve the basic system reliability. When improved cargo reliability or improved cargo ride is sought, more study, analysis, and action addressed toward highway shock control are essential.

For intermodal shipments, the highway shock environment is an interacting portion of the total transportation shock environment. This interrelation was emphasized during a recent shipment of containerized ammunition. The cargo was restrained at the ammunition manufacturing plant to resist shocks for all modes. Consequent to highway shipment from the plant to the ocean port, normal vertical shocks caused damage to the vertical cargo restraint members. The restraint parts damaged were required to restrain the cargo during the ocean portion of the shipment and had to be replaced or repaired in advance of the ocean shipment. Vertical cargo restraints have to be designed to withstand highway shocks that are damaging not to the cargo but to restraint system components that work farther along the route. The desired procedure is to restrain one time for all modes so that rehandling and reinspection are minimized.

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Frequently, in highway transportation a shipper can pay additional costs for improved cargo ride and yet receive the same or higher shocks transmitted to the cargo. This occurs because the relation among highway, highway vehicle, cargo mechanics, cargo restraint, and accumulative effect of other modes of transportation either has not been developed or has not been communicated in a practical procedure. Traffic managers order or specify generally the mode, the type of equipment, the route, and the cargo restraint. Packaging requirements are frequently set up independently. All of these factors affect the shocks transmitted to the cargo. Extra money spent to improve one factor may not affect the overall system and, in extreme cases, could even result in more transportation money being spent and the system being worsened.

Transportation research and development tend to hit on one or more interrelated areas and to result in component improvement that is not necessarily a system improvement. When system improvements are made, rarely does feedback to the improvers occur, mostly because there exist no performance terms that are common to research manufacturing and operations.

There is a most pressing need to expend the necessary effort to organize highway transportation ride-attributing characteristics into qualified terms that can be communicated practically and related properly to the total system. In this connection, a uniform system that references pavement roughness could provide a valuable index for predicting ride characteristics correlated with a shock and vibration "signature" of a system. During the past several years, the military transportability agents have addressed themselves to a ride signature.

The first 2 areas approached and discussed in this paper are shock classification of highway vehicles and cargo-restraint system classification. Considerable shock and vibration work has been conducted for particular cargo-vehicle combinations. The efforts here are geared to benefit the majority of military cargoes that are not in the category of those now receiving adequate attention. General cargo items will profit most from classification and organization.

An interdepartmental agreement was formed among the Army, Air Force, Navy, and Marine Corps to sponsor and pursue jointly programs designed to improve transportation with regard to shocks and vibrations to the cargo. A steering group was formed of one representative from each participating agency. Consequent to steering group meetings, the highway mode was selected for initial pursuit, and the concept of static measurements to predict dynamics performance for vehicle load configurations was established. A jointly sponsored procurement was let to General Testing, Inc., Springfield, Virginia, to develop a shock index (SI) equation based on actual static and dynamic measurements. An advisory group of representatives from National Bureau of Standards, National Academy of Sciences, Department of Transportation, National Aeronautics and Space Administration, and Aerospace Industries recommended that prior to release SI formulation be verified by a separate contractor. J. A. Johnson, Inc., Short Hills, New Jersey, was awarded the verification contract and has recently completed this work.

SHOCK INDEX

The SI formula was developed in a straightforward fashion. Because of the wealth of instrumented test runs, most of the important static vehicle characteristics contributing to the shock and vibration to the cargo were known. These include static spring rates, relative size of the truck trailer, percentage of the rated load, and cargo. Test runs were made with vehicles that had measured static characteristics and instruments affixed to measure the shocks transmitted to the cargo. The resulting data were then fitted mathematically to produce a formula that would express SI in terms of the measured static characteristics. The SI is a function of the severity of the accelerations transmitted to the cargo.

The SI range was set from 1.0 for the worst riding vehicle load configuration to 5.0 for the best. The SI values are a proportioned inversion of the acceleration readings to set higher values for better vehicles. Also the SI range was set to match with present serviceability index (PSI) described by the Highway Research Board (1). The PSI also ranges from 1.0 for the worst road pavement to 5.0 for a near perfect pavement.

The results of the efforts described above have produced the following formula:

$$SI = \left\{ 4.5 \left[\frac{(A + B) - (C + D)}{A + B} \right] \left(0.5 + \frac{4K_L K_S + K_L^2 - K_S^2}{4K_L K_S + 4K_S^2} \right) - 0.53 \right\} (\log \text{percentage of rated load} - 2.25) + \frac{(M + N)\ (P) + (S + T)\ (U)}{(F + G)\ (P) + (I + J)\ (U)} + 4.92$$

where

A = combined front weight, rated load at any position;
B = combined rear weight, rated load at same position as A;
$A + B$ = maximum rated gross weight;
C = combined front weight, no load;
D = combined rear weight, no load;
$(A + B) - (C + D)$ = maximum rated net weight;
K_L = greatest combined suspension spring rate, front or rear;
K_S = least combined suspension spring rate, front or rear;
F = combined front suspension deflection, rated load located forward;
G = combined front tire deflection, rated load located forward;
I = combined rear suspension deflection, rated load located rear;
J = combined rear tire deflection, rated load located rear;
M = combined front spring deflection, rated load at test position;
N = combined front tire deflection, rated load at test position;
P = combined front weight, rated load at test position;
S = combined rear suspension deflection, rated load at test position;
T = combined rear tire deflection, rated load at test position; and
U = combined rear weight, rated load at test position.

Figure 1 shows the spread of predicted versus actual values of accelerations transmitted to the cargo. Each point on the curve represents the maximum value for 1 test run used in the development of the curve. The goal was to keep the predicted values within a bandwidth of 1.0 SI for 95 percentile shock readings. The values shown for development tests represent all extreme loading configurations and the maximum acceleration reading. The results of these test runs and analysis indicated that maximum shocks are indeed responsive to changes in the static characteristics of the vehicle load configuration.

The basic plan for SI is to start with loose tolerance to see whether it has value and then to proceed to broader cargo coverage and more precision. The SI now applies to frequencies below 60 cycles per second, a 95 percentile shock acceleration, and a threshold on the acceleration count of 1.0 g. Also, SI is developed and based on extreme values for shocks. All factors, including the road surfaces, were selected to produce maximum readings. Typical cargoes will rarely have severe road conditions associated with speeds, weights, and mechanical combinations used for formula development. The severe shocks and factors causing them are what the SI will classify for control purposes.

Many other mechanical factors that do not appear in the SI formula contribute to shocks. The mathematical process of formulation eliminated factors whose contribution was outside the range of sensitivity of the SI. The highest contribution to the shock was the percentage of rated load factor. Figure 2 shows that for a typical standard truck the SI will range from 2.5 for 10 percent load to 4.8 for 100 percent load with all other factors remaining fixed.

It was deemed important to verify the formula by using it for actual vehicle cargo configurations and to check the predictions with instruments by making a test run over public roads. A short public road test course consisting of a portion of Interstate highways, secondary roads, railroad crossings, and gravel roads was chosen for reproducible input. Eighteen vehicle load configurations covering different types of tractor-trailers, load placement, and cargo weights ranging from 10 percent rated load to maximum allowable load were selected to give reasonable coverage. All test runs were made at maximum legal speed. The data came within a 1.0 SI bandwidth for the more practical high load range and are judged useful for control of highway shocks to the cargo. Further formula improvement should draw all of the data within the 1.0 SI bandwidth. As part of the SI verification program, test runs were made over the same test course at speeds lower than the maximum legal speed. Reductions in acceleration with reduced speed are most pronounced and consistent with maximum loads.

The principal use for the SI is to improve communications among traffic management, packaging, design, and operations personnel. It is planned to use the term SI as the term "octane rating" is now used for gasoline. SI is not intended at this time to be precise, but it will fill a large void where no term or numerical factor is available to classify highway cargo vehicles with regard to their ride potential. Future plans call for extending the range of SI to cover a range of highway speeds, incremental load variations, lower threshold acceleration, higher frequencies, and a higher extreme value for significant accelerations.

An example of effective utilization of the SI concept is the development of a cargo-restraint system. Once the vehicle and the pavement have numerical classifications, the need for definitive and calculable cargo restraint is apparent. The 3 classifications need all be known to improve the predictability of the shocks transmitted to the cargo.

Intermodal considerations consequent to containerization have pressed for more definitive factors relative to shocks transmitted to the cargo during highway shipment. Highway transportation for containers is but one part of a larger intermodal transportation system. Shocks occurring during highway moves accumulate and add to the loss and damage figure for the entire shipment. Cargo is restrained in the containers one time for an intermodal shipment, and the method of restraint must be designed for the entire trip, which calls for design compromises for individual mode restraints. Many existing highway restraint systems are not rigid in the vertical direction because, during cargo bounce, the cargo returns to substantially the same spot. Rigid vertical restraint is required for other modes and needs to be strong enough to withstand highway verical accelerations.

The Military Traffic Management and Terminal Service (MTMTS) cargo-restraint system shown in Figure 3 was developed for use as in intermodal cargo restraint. The cargo is completely secured to the floor, which eliminates the uncertainties of end, door, side, and roof strength with regard to dynamic loads imposed by the cargo.

Of primary importance is the feature that the system is structurally simple and that the strength and margins of safety can be calculated with accuracy for individual cargoes.

Comprehensive transportability tests of the MILVAN container system fitted with cargo-restraint systems are in process of the U.S. Army Materiel Command Ammunition Center at Savanna, Illinois. The tests are organized into 6 separate phases as follows:

Phase	Method
Highway in service	C
Terminal handling	B
Rail	B
Highway	B
Terminal handling	A
Rail and highway	A

Method A tests are proof tests used to certify the system. Method B tests are failure tests where the load is increased to the point of structural failure to determine

Figure 1. Predicted SI versus recorded acceleration for 5 vehicles.

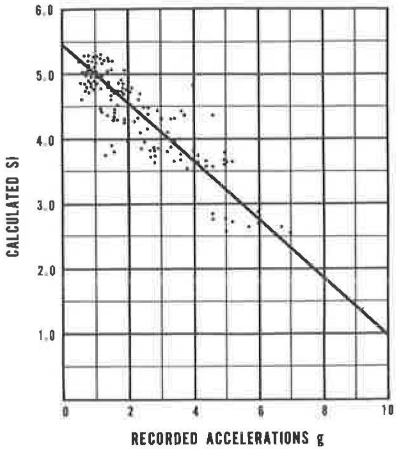


Figure 2. Effect of cargo weight.

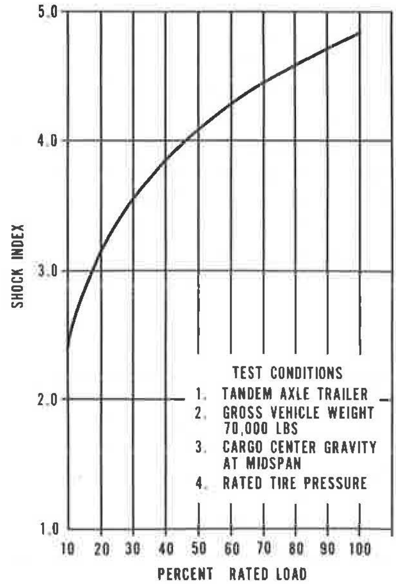


Figure 3. 105-mm ammunition secured with JK-1 cargo-restraint system in MILVAN container.

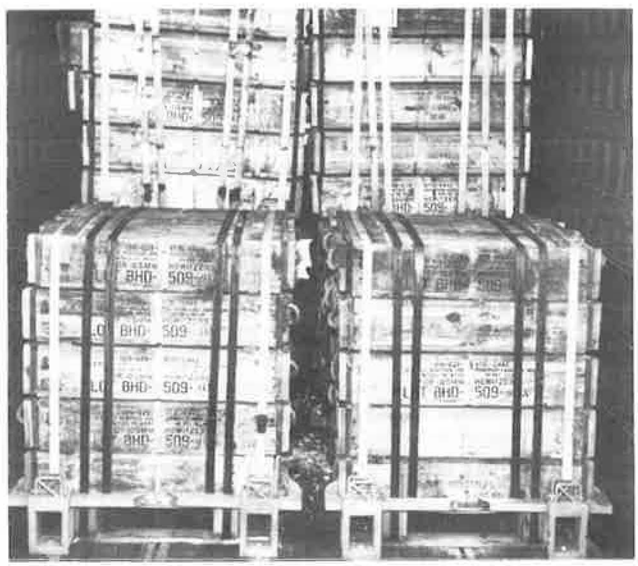
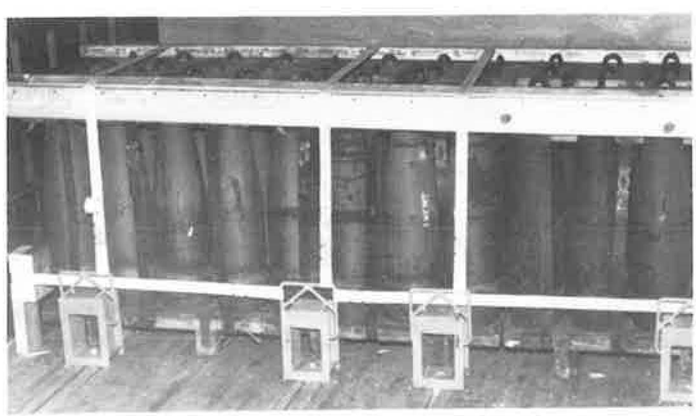


Figure 4. 155-mm ammunition secured with JK-2 cargo-restraint system in MILVAN container.



the failure loading and a margin of safety. Method C tests are instrumented tests of the cargo during actual shipment. The first 2 phases are complete, and the entire program is scheduled for completion in May 1972. Figure 3 shows 105-mm ammunition restrained in a MILVAN container with the JK-1 restraint system. Figure 4 shows the last row of 155-mm ammunition restrained in a MILVAN container with the JK-2 restraint system. The lateral restraint for JK-1 is built in the floor chock, whereas the lateral restraint for the JK-2 is accomplished with horizontal steel straps. When the test program is completed, failure loads and margins of safety will be developed for all components that are marginal for any of the complete assortment of transported shock and vibration loadings.

Preliminary analysis shows that the MTMTS cargo-restraint system is lighter, costs less, and is more predictable than systems now in use. It eliminates the need for lumber dunnage. Current blocking for ammunition requires approximately 800 to 1,800 lb of lumber per 8- by 8- by 20-ft container. This saving is more important from a natural resource conservation standpoint than it is from cost considerations.

The restraint system will give good reproducibility in strength performance, and that will tend to eliminate underdesign or overdesign. Its potential for numerical classification should help close the loop of numerical PSI's and SI's. The restraint system will prove most valuable for intermodal shipments where the cargo can be secured on time, based on the numerical strength classifications for all modes of transport and terminal handling provided.

CONCLUSIONS

A need exists to organize transportation systems for practical risk determination applicable to loss and damage consequent to transportation shocks and vibrations transmitted to the cargo. The 3 prime areas addressed are pavement conditions, vehicle suspensions, and cargo restraints. AASHO has made a good start with the concept of numerical classifications of pavements (PSI). The interdepartmental group appears to have numerical vehicle classification well started with the SI concept. MTMTS has shown one restraint system that can be numerically rated and that gives reasonably consistent and reproducible performance.

All concepts are general and broad and provide an opportunity for building comprehensive and practical organization of transportation shock and vibration control. Future areas to build include the development of interrelation among SI, PSI, and cargo restraint. All areas can be improved to include shock prediction for a more sophisticated range of cargoes. Expansion is also planned for more precise classification of all numerical factors with regard to speed, load variation, road types, automatic handling of cargo, and projection for research and development.

Standardization for pavement PSI and procedures for determining it require attention both nationally and internationally for the numerical values of the PSI to be complementary to the other rating factors. Effort is needed now to achieve standardization. Similar SI's are required for rail, sea, air, and terminal handling, and the interdepartmental group plans to arrange for and jointly sponsor development. This work affects industry, research associations, commercial operators, and the military. Cooperation, encouragement, and interest in this work are requested.

REFERENCE

1. The AASHO Road Test: Report 3—Traffic Operations and Pavement Maintenance. HRB Spec. Rept. 61C, 1962.