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Progress on Bridge Loading

Progrès dans la charge des ponts

Fortschritte bei der Erfassung der Belastung von Brücken

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Report on the Proceedings of a Colloquium on Highway Bridge Loading. Cambridge, 1–10 April 1975 Organised by the British Group IABSE

General

Thirty six papers were contributed to the colloquium. The procedure adopted was that all papers were circulated to participants well before the date of the colloquium so that they could be read and digested, enabling the participants to be ready and prepared for the discussions at Cambridge. The procedure was eminently successful; all papers were in the hands of participants in adequate time and were clearly studied very thoroughly.

The various papers are individually of such value that it has been decided not to summarise them in the published report. They are available in full from the British Group. A list of the papers and authors is appended.

This report is a substantially abbreviated version of a much fuller report which is also available from the British Group. It attempts to review the substance and general conclusions of the very active discussions which took place over three days of concentrated application by the participants. It contains no extracts from the submitted papers for the reason given and does not attribute any statements to individuals since its object is to attempt to present a consensus of opinion. The author accepts full responsibility for his interpretation of this consensus.

Very considerable thanks and appreciation are due to the participants who produced much valuable work and devoted themselves to a very strenuous and intensive discussion.

All countries appear to have similar problems in respect of the classes of traffic which use their highways. Broadly, traffic can be classified into three groups.

(a) Normal vehicles designed to conform to the general legal limits imposed in each country. These normal vehicle weights range in maxima up to some 400kN gross laden weight. This weight is fairly typical of most countries. In Ontario, Canada, however the permitted laden weight can be as much as 700 kN.

(b) Extra Normal vehicles, typified by engineering construction equipment, the gross weight of which ranges up to some 1,500kN. The movement of this type of traffic is generally subject to some degree of control by law but enforcement of the controls appears in most countries to be fairly limited in its efficiency. There is, therefore, with these vehicles a not inconsiderable risk of them travelling on routes where it is undesirable they should be.

(c) Abnormal Vehicles, which are special vehicles designed to carry indivisible loads of considerable weight such as electricity transformers and other heavy electrical plant. Loads up to some 6,000kN are to be considered in this group for which movement is in general closely controlled in most countries.

Whatever the form in which vehicular loading is presented for bridge design purposes it is a model and should be clearly recognised as such by those who apply it. The weight and disposition of vehicles varies from instant to instant and from bridge to bridge; the loading model must embrace the most severe effects of well defined categories of vehicles.

The view was taken that there should be one design loading model to represent traffic of categories (a) and (b) and another model to represent vehicles in category (c).

One of the defects of some design loading models in use in the past has been that while they catered for normal traffic reasonably well they did not do so satisfactorily for extra normal traffic; for medium and longer span bridges the main longitudinal members could sustain quite large overload effects due to these category (b) vehicles but short secondary members were severely limited. It was considered that any satisfactory traffic loading model for general application should be contrived to eliminate this defect and to produce a reasonably consistent overload capacity in all elements of a bridge.

With very few exceptions the view was taken that the most satisfactory form of model is a uniformly distributed load associated with one or two point loads. The point load or loads are intended to provide the necessary adjustment required to make it possible for one uniformly distributed load to be used for both bending and shear on the smaller elements of the bridge structures and also, of course, for the shorter span bridges.

Due to the mix of traffic, ranging from private cars (generally by far the largest number of vehicles using a highway) up through several gradations to the heaviest truck to be considered (generally a quite small proportion of the traffic) consideration must be given to the attenuation of the vehicular loading model as the loaded length becomes greater. On a short loaded length it is a reasonable expectation that it can be filled with closely packed vehicles of the heaviest type. As the loaded length increases the interspersion of lighter vehicles will reduce the equivalent intensity. The characteristic load is not sensitive to the nature and mix of the traffic for short and medium loaded lengths but does become very sensitive to these as the loaded length increases.

It is also the case that as the width of carriageway increases in terms of the number of traffic lanes available so too will the characteristic load decrease across the carriageway.

Several views were offered on how the loading model should be constructed to take these phenomena into account in respect of longitudinal attenuation;

(A) That the intensity of the distributed load in a traffic lane should be taken as constant over short and medium loaded lengths and thereafter diminished in a smooth curve as the loaded length increases.

(B) That a constant distributed load occupying a discreet loaded length of around 30 m should be taken and a series of these loaded lengths considered with gaps of no live loading between, the gaps progressively increasing in length as the total overall length under consideration increased.

The important consideration to be kept in view is that whatever device is adopted, the severe intensities associated with short and medium span structures must also be expected to occur on long structures and to occupy the same loaded length as is appropriate to the medium span bridge. These high intensities must be considered as occupying that part of the influence line with the largest ordinates.

While this is self evident when applying an arrangement of distributed load such as is described in (B), it can and should be applied with the arrangement described in (A) also.

In respect of transverse attenuation two devices were again presented;

(C) That one or two lanes should be considered to be occupied by the full intensity of uniformly distributed load appropriate to the loaded length concerned and that all remaining lanes should be considered to be occupied by a stipulated fraction of the appropriate full intensity (say 1/3).

(D) That the effect of multiplicity of lanes in the width of the bridge should be regarded simply as an extension of the treatment of the attenuation of uniformly distributed load in relation to the longitudinal loaded length. In applying this device the longitudinal lengths of each lane would be summed and the total load taken on the bridge would be represented by the product of this total loaded length and the appropriate intensity of distributed load associated with it. Where, however, elements of the structure were severely affected by shorter loaded lengths as, for example the length of one lane or part of a lane, the intensity of load appropriate to this particular loaded length would be applied within it and the remainder of the total for the whole bridge allocated to other lanes.

It remains to be established whether or not the patterns and disposition of traffic in adjacent lanes of a multi-lane highway are affected in the same way as is the case for increasing lengths of any single lane.

Although, the prevailing view was that a uniformly distributed load with one or two point loads provided the most satisfactory model there was, nevertheless, a strongly held conviction of a few participants that for short and medium loaded lengths it was most satisfactory to specify a pattern of trucks, reserving the distributed load concept to long loaded lengths.

Methods of Derivation of Loading Models

In the submitted papers there is a number of most excellent studies of statistical techniques and information presented. It remains, however, that there is much yet to do in the way of collection of data related to traffic weights and disposition on the highways and the formulation of trends oftraffic behaviour. Among the aspects which call for study is the formation of convoys of heavy trucks, both as a consequence of the "properties" of different types of vehicle and as a result of the deliberate decision by organisations or drivers. By "properties" is meant relative operating speeds, manoeuvrability and other characteristics. It will no doubt also be necessary to extend the studies to take into consideration the "properties" of different kinds of highways. Studies are also desirable of traffic behaviour in special circumstances (accident, unexpected road block, throttling of traffic by unexpected reduction in the number of lanes at some point in an otherwise wide and free running carriageway). Basically there is also the need to collect data concerning the weights and spacings of axles and their sequence in different lanes of carriageways, taking into account that trucks are frequently not carrying their maximum capacity in terms of weight although they may be in terms of volume.

It was generally agreed that while probabilistic studies based on thoroughly researched data were of vital importance the derivation of a loading model could not be based on these alone. The final form and intensities of the traffic loading model would have to be based on the "credibility" approach supported by the probabilistic studies. These studies would contribute towards the important objects of;

1. Achieving a consistent standard of safety.

2. Ultimately establishing a quantified level of risk.

3. Reinforcing confidence in the adequacy of the loading model.

One of the serious difficulties in using the "credibility" approach is that on short loaded lengths where it is clearly feasible that a tightly packed group of the heaviest trucks could be present, the only way in which excess loading could be occasioned would be the overloading of vehicles. For this there is little room for doubt, but on long loaded lengths where the intensity of loading is diminished to reflect the attenuation of traffic it becomes possible to speculate on situations where the traffic <u>might</u> consist of an exceptionally large number of the heaviest trucks which might become closely packed because of some blockage, while it might be that some of these trucks were grossly overloaded and these might unfortunately occupy the region where the influence line ordinates are largest. While this statement clearly is grossly exaggerated it nevertheless points up the contribution which probabilistic studies can make to (3) above.

Assuming that loading models are already in use, as they are in most countries, the development of well founded probabilistic studies related to various loaded lengths should make it possible to re-shape the model accordingly as the level of risk has been over or underestimated at different regions, thus achieving the objectives (1) or (2) above.

In this respect it is worth noting that for the small or moderate span bridge where the loading model is likely to be most realistic, quite large changes in design loads will have only minor effects on cost. On the other hand in large span bridges where the greatest uncertainty is, and the tendency is that the loading model is likely to have been made unduly severe, the cost of providing the strength to carry excessive traffic loading becomes substantial.

The problem remains at the present time, when the amount of statistical work done falls so far short of the desirable, how should an acceptable level of risk be established? The problem is not made simpler by the adoption of limit state design philosophy. It was considered that no serious attempt should be made to quantify the probabilities in numbers, but rather that the development should be made from experience of live load models used now and in the past. Are existing bridges safe for the levels of traffic we have today? If so, this state should be preserved. Comparisons can be made by equating the design loading effects when applied to established "permissible working stress" methods with the effects when applied to "limit state" methods and a suitable load factor derived. Since former methods generally used the same factor for dead loads as for traffic loads, while the latter method introduces low load factors for dead load, where there is a greater degree of certainty about its amount, it follows that the two methods can only be equated at one selected ratio of dead to live load and this must be chosen as a satisfactorily low value.

Vehicle regulation in law and changes in the future

A satisfactory standard of law enforcement in respect of the laden weights permitted on heavy trucks was considered essential, as was also the control of the weights and movements of these vehicles classified as extra normal and as abnormal.

The permitted weights of vehicles and the safe carrying capacity of bridges are intimately associated. It seems remarkable therefore that few states appear to use their highway bridge traffic loading model directly as a datum which also controls what may be permitted as maximum laden weights in their vehicle regulations. Only in Great Britain and Ontario it appears is there a deliberate formulation of permitted vehicle weights directly in terms of bridge loading.

In discussing the allied problem of the extent to which the loading model should anticipate future trends in the development of vehicles in terms of permitted weight it was generally conceded that this was something which could not be done in any developed country on a rational basis although some attempts had been made to do so on a short term basis to the extent of around 10%. The fact is surely that any developed country has such a great capital investment in existing bridges that it is not conceivable that all of these should be made inadequate by a decision to introduce substantially greater carrying capacities.

In developing countries which presently may have comparatively light traffic it is possible to predict with a degree of confidence that traffic weights will trend towards those of developed industrialised societies and it is considered that the capital investment being made in new bridges should take this into account. Development and industrialisation can be seriously inhibited by inadequate bridge capacity.

Category C Vehicles All industrialised countries have the problem of moving exceptionally heavy, generally indivisible loads of industrial, frequently electrical equipment such as transformers, generators, large presses, even ships propellors, rudders, stern frames and the like. The needs of different countries tend to differ in accordance with the prevailing industrial activities and the existence within the country of other forms of transport such as railways and waterways capable of carrying these loads.

The extent to which highway bridges should be constructed to cope with these is very much a matter of the economics of each country. Few, if any of these loads are indivisible in the absolute sense, but simply are more cheaply and satisfactorily built in some factory equipped to construct them economically. To what extent bridges and routes should be designed to carry such loads is a matter of balancing the economics of constructing an adequate route against these other considerations, giving due account to the considerable nuisance these loads are to other highway users.

The number of these vehicles in any country is not large and they are generally of much the same configuration. Because of this the most appropriate model to be used for bridge design is an idealised vehicle. The movement of these vehicles on the roads is normally very strictly controlled; given the extent to which this control is reliable it is open to decide the extent of normal traffic which ought to be considered to be with these loads on bridges.

Dynamic Effects

Braking Forces There appears to be a very wide variation in the specified requirements of various countries. It was considered that this was an area where a review of these requirements was desirable. The increased adhesion possible between road surface and vehicle, the increased speeds of heavy vehicles and the use of elastomeric bridge bearings and piers which flex to accommodate temperature movements of the deck make it desirable that adequate braking forces should be specified. Two aspects of traffic should be considered, the first being several heavy trucks following each other at a speed appropriate to them and spaced out as they would be at that speed. An emergency application of brakes in the first truck would be followed by a similar application successively in the following trucks so that over a calculated period of time several trucks would exert the maximum braking force simultaneously. The second aspect would be the collision of one fast moving heavy truck with some other stationary but substantial truck or other object which might be disposed in such a way that progressive collapse of the latter would not dissipate a large proportion of energy.

Centrifugal Forces For much the same reasons as for braking forces a review of these was desirable. The succession of heavy trucks suggested for that effect would also be an appropriate condition to be considered for centrifugal forces.

Impact Effects Defining these as the outcome of dropping a mass on to a surface and also the sudden application of mass to an element, the former could vary quite considerably from country to country, depending on the standards of road construction and maintenance.

Little study appears to have been done on the effect of sudden application of loads to elements with very short loaded lengths, some of which may in fact have a cantilevered form where a wheel may exert its maximum effect at the instant of its first contact with the element (plates at expansion joints are an example); further investigations into this aspect are desirable.

Vibration and Damping There was general agreement that impact loading and dynamic response, though closely related should be treated separately so far as the effects on a bridge and its elements were concerned. The specification of a standard impact factor together with a maximum permitted deflection per unit of span is not considered to be an adequate or satisfactory check for the dynamic response of a bridge.

The calculation of the natural frequency should constitute part of the normal design procedure. Suitable approximate methods are given in papers submitted. Dynamic response can lead to the equivalent of an increment in vertical load which has been treated as part of the impact factor but preferably should be considered separately; where the vibration mode of the element is below 4.5Hz the value of this vertical increment of load can be substantially increased.

Vibration is of particular significance on footbridges where discomfort and alarm may be caused to the user. Tolerance levels are discussed in submitted papers.

The damping capacity of bridge structures has not been adequately researched and knowledge in this area is severely limited. Further work in this subject is strongly recommended and should be rewarding.

Fatigue Dealing first with stress cycles due to the dynamic response to vehicles, surveys of heavy vehicle behaviour have shewn that with normal traffic flow there is little interaction due to the pressure of several vehicles. One stress cycle per vehicle with a 6% amplification of the static stress (giving a 1.2 factor on damage) would provide a reasonable basis in this respect.

The random variable stress cycles due to the passage of traffic can be related to design strengths derived from sinusoidal constant amplitude data using either Miner's cumulative damage rule or the Root mean square-stress range relationship. Both methods are dealt with in submitted papers.

Load Spectra should be based on observed national traffic and vehicle load conditions. These require to be extensively and thoroughly studied and reliable observations made of vehicle spacings, range of proportions of maximum load carried, alignment of successive vehicles behind each other and so forth.

It is believed that there is a strong tendency to make cumulative over-estimates of the stress ranges when making assessments a priori from limited data. The view was expressed that the load spectrum should vary in accordance with the locale of the bridge and that it should vary in accordance with the span.

The fatigue threshold is not well defined under high cycle (10 to 100 x 10^6) variable and constant amplitudes and further research is desirable in this area. So too is the need to develop techniques in fatigue monitoring and crack detection having practical application to bridges. Since the pattern of variable stress cycles and the number of cycles cannot be predicted with any degree of precision the same applies to the prediction of the initiation of cracks. Currently available monitoring devices (magnetic and acoustic instruments) have not been effective and painting which is essential to prevent corrosion obscures any fine cracks effectively,thus it is unlikely that any crack will be visually observable until it has opened quite significantly. It was agreed that some sort of displacement induced stress indicator should be developed towards this object and installed in steel bridge structures.

It was emphasised that strength in fatigue relied essentially on good detailing. Specifications should be framed to encourage designers to use good details and stringent quality control should be exercised at all stages during fabrication and erection. With these provisos it was general felt that fatigue was probably not such a serious problem as it was thought to be by many authorities.

So far as corrosion fatigue is concerned it was considered that in normal environments with reasonable maintenance this was not a matter for concern.

The question of the design life of bridges was discussed. Several countries do not appear to specify this. It is, of course, necessary in dealing with fatigue in order to assess the number of cycles of stress to be considered. It is also essential in limit state design in order to establish partial factors which are time related. Some participants were, however, of the opinion that for the latter purpose the "life" could be taken as substantially less than the planned life of the bridge.

Collisions with Piers and Parapets Useful contributions were made on this subject. These deal with the control and containment of light vehicles such as private cars and also heavy trucks, but a great deal more work and study is required in the latter field. Calculation of the resistance to collision using dynamic methods related to energy dissipation is the most attractive approach to providing realistic and flexible solutions for specific situations as opposed to the rather arbitrary requirement of a strength to withstand a static force.