SEISMIC DESIGN OF BRIDGES

SECTION 1

DESIGN PHILOSOPHY

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1.1 INTRODUCTION

Earthquakes are random occurrences and a statistical approach involving consideration of the return period is called for when choosing the design intensity. The return period is defined as the reciprocal of the probability of the event being equalled or exceeded in any one year. It is the mean interval between successive events at that level, taken over a long time.

The design philosophy recommended for the provision of earthquake resistance for bridges, is based on the requirement that communications should be maintained to an appropriate standard after all earthquakes. Ideally, this would be achieved by ensuring that there is an acceptable probability of damage occurring during the life of the structure, at three broad levels of intensity of earthquake motion. The three levels are defined as follows:

(a) In earthquakes with return periods less than 50% of the life of the bridge, and thus likely to occur a number of times during its life, damage should be minor, and communications should not be disrupted.

(b) In earthquakes, with return periods between 50% and 150% of the life of the bridge, considerable damage may occur, but the bridge should not collapse. The bridge should be usable by emergency traffic after simple and rapid repairs, and should be capable of permanent repair to an acceptable level of both vehicle and seismic loading. The extent to which this is pursued will be determined by the controlling authority.

(c) In earthquakes with return periods greater than 150% of the life of the bridge, damage may be extensive, but the bridge should not collapse. It should be usable by emergency traffic after temporary repairs, and may be available for use, perhaps at a lower level of vehicle loading, after permanent repairs.

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As it would be impracticable to investigate the performance of structures at all three levels of loading in every case, it is recommended that only level (b) should be considered for routine design. It is expected that if the design criteria for this level of loading are satisfied, the performance at the other levels described will also be satisfactory.

1.2 ASSESSMENT OF SEISMIC DESIGN LOAD

The seismic design load is based on an envelope of elastic response of structures to earthquakes of a specific return period, in the appropriate seismic zone. A specific percentage of critical damping has been assumed in determing the envelopes.

In most cases it is considered uneconomic to design a bridge structure to resist severe earthquakes without providing means to dissipate the large amounts of energy which will be imparted to it by earthquake action. If energy dissipation can take place, the seismic design loads will be less than the elastic response inertia loads. In consequence, it is recommended that the design concept should generally be aimed at providing reliable means of dissipating energy, either by detailing certain structural elements (usually piers) to be ductile, or by providing supplementary energy dissipating devices.

The level of seismic design load may be decreased as the design level of ductility increases (up to a specified limit), according to an equal displacement concept for long period structures or according to a more stringent concept for short period structures.

1.3 DESIGN LIFE AND EARTHQUAKE RETURN PERIOD

1.3.1 General case under design earthquake

The design life is not normally a parameter which is specifically stated in current design criteria, but it is considered that 100 years is a reasonable figure to use for this purpose for the majority of bridges in normal circumstances. The combination of this life with a 150 year earthquake return period will therefore satisfy the criteria of 1.1 (b) above. This combination is considered to be appropriate for the following reasons:

(a) It produces a level of seismic

design load similar to that currently in use. Capacity to resist this level has been found from experience to be obtainable at reasonable cost (5 to 10% of total cost of the bridge), provided that the designer considers it at the outset of the design.

(b) The risk of damage, and the associated cost of repair during the life of bridges designed to this level is considered to be acceptable.

(c) The combination of 150 year return period with 100 year design life implies a probability of approximately 0.5 that the design earthquake will be exceeded during the life of the structure.

1.3.2 General case under extreme earthquake

If structures are designed to satisfy the requirements of 1.1 (b), it is expected that they will also satisfy the requirements of 1.1 (c). During these larger earthquakes with longer return periods there will be increased demand for energy dissipation but it is expected that this demand could be met by a well designed structure. This is a consequence of the following factors:

(a) The actual strengths of earthquake resisting members are likely to be greater than assumed for design, because they will be based on minimum likely material strengths and the use of strength reduction factors. The effects of steel strain hardening and confinement of concrete will further increase the actual strengths.

(b) Due to greater movement between structural elements, and movement of foundations in the ground, the damping is likely to be greater than assumed.

(c) Under the action of a very large earthquake, extensive loss of cover concrete and yielding is likely to occur, thereby lengthening the natural period of vibration and usually reducing structural response.

(d) The displacement ductility factor which the designer uses to determine the design load will be the minimum dependable value. For a well designed and detailed bridge, a larger figure is likely to be achieved in practice.

1.3.3 Bridges of less than average importance

Notwithstanding the ideal approach described above, it is acknowledged that there are many circumstances where it is not feasible or not economic to provide a significant amount of ductility, and is not economic to accommodate the large inertia forces resulting from the 150 year event. In such circumstances, the bridge may be designed for a smaller return period. The use of 100 or 50 years would imply probabilities of 0.63 and 0.87 respectively that the design earthquake will be exceeded during the life of the structure. The justification for using these reduced periods will be the importance of the bridge to the community, and this will be determined by the controlling authority.

1.3.4 Bridges of greater than average importance

Conversely, there will be bridges which may be termed "lifeline structures", which are essential to communications, especially after a disaster, and which require greater than average protection. If such a bridge is designed for a 250 year return period, this implies a probability of 0.33 that the design earthquake will be exceeded during the life of the structure. These structures will be identified by criteria laid down by the controlling authority.

1.3.5 Bridges of other than normal design life

A major structure may well be considered as having a design life in excess of 100 years. Conversely, when considering a temporary structure or the addition of seismic protection to an existing one, the design life may be considerably less than 100 years. In both cases, the return period should be selected to give a probability of exceedance not greater than that of a bridge of similar importance designed for 100 years life.

1.4 THE DESIGN PROCESS

The assessment of the design seismic load is of course only part of the design process. Many related problems must be considered, and the results integrated to produce an efficient design. There are three basic skills:

1.4.1 Concept

The first skill is the ability to conceive in detail the best structural form. The process will include a number of specific considerations, all of which must also be assessed for the effect on the behaviour of the bridge in resisting loads other than seismic. The designer should not forget that even though seismic considerations may govern many parts of the structure, its primary function is always to carry live load.

Specific considerations are:

(a) The bridge may be a framed structure, a continuous superstructure on bearings, a simply supported superstructure, or some combination of these.

(b) The materials used may affect the dead load, (and hence the seismic load), the flexibility and the ductility attainable with a particular configuration.

(c) One or any number of the supports may be used to resist seismic forces.

(d) A balance should be maintained between displacement and strength requirements. In general, greater flexibility decreases the response and hence the seismic loads and cost of supporting members, but increases the movements at joints and hence their cost and the risk of damage there.

(e) Ductility at any location will improve the ultimate behaviour, but there is an arbitrary limit on the amount which can be used to lower the level of design seismic load, and it is possible that the economic limit may be lower than that in some cases.

(f) The number and location of energy dissipating points must be chosen, whether they are to be plastic hinges in structural members or specific energy dissipating devices. Alternatively, the structure may be designed to remain elastic at design earthquake level in some cases.

(g) A choice of the number and location of movement joints must be made, and whether they are to accommodate translation as well as rotation and whether seismic translation or only length change effects.

(h) The locations at which damage is to be expected under severe motions must be identified and the difficulties involved in repairs considered.

(i) All of the above must be considered in relation to earthquake forces in all three orthogonal directions.

The ability to effectively consider all the above items is something which can be gained only through extensive experience of many types of structure. Simple adaption of non-seismic designs is impractical as extensive modifications (often prohibitive) must always be made. This is especially true in the case of a major bridge, where particular care is necessary to ensure serviceability after an earthquake. Normally several trials will be necessary to obtain the best solution. These trials should be examined bearing in mind the cost of providing the earthquake resistance, which must be commensurate with the value and importance of the structure.

1.4.2 Analysis

The second skill is the analytical ability to estimate the response of the particular structure. In many cases this is difficult, particularly the assessment of interaction between the soil and the structure, and considerable theoretical knowledge is required. This branch of earthquake engineering is undergoing continual development as new techniques are brought into use. Notwithstanding the complexity of the analysis, the choice of a simple structural form is to be preferred, since the performance of such a structure will be more reliably predicted.

1.4.3 Detailing

Finally, the bridge must be carefully detailed so that all parts of it behave reliably, and in accordance with the designer's intentions. This will involve "capacity" design in which the primary energy dissipating elements are chosen and suitably designed and detailed, and all other structural elements are then provided with sufficient strength so that the chosen means of energy dissipation can be maintained throughout the deformations which may occur. An equally important aspect of detailing is that of the movement joints, particularly those which are intended to accept translational seismic movements. Adequate clearances between structural members must be provided for seismic movements, which are often large compared with those resulting from length change effects. The economical design of joints to cater for both requirements calls for extreme care.

As site conditions may dominate structural response, the bridge displacement may well be much larger than that indicated by even the most sophisticated analysis. Judgement will be required and high levels of ductility and generous movement gaps will be often economically justifiable.