SEISMIC DESIGN OF BRIDGES

SECTION 6

MECHANICAL ENERGY DISSIPATING DEVICES

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CODE:

6.1 The following criteria are to be satisfied for design of bridge structures incorporating flexible mountings and mechanical energy dissipating devices.

6.2 The performance of the devices used is to be substantiated by tests.

6.3 Proper studies are to be made towards the selection of suitable design earthquakes for the structure, taking due account of local site conditions.

6.4 The degree of protection against yielding of the structural members under the design earthquake is to be at least as great as that implied in these recommendations relating to the conventional seismic design approach without energy dissipating devices.

6.5 Where possible, the structure is to be detailed to deform in a controlled manner in the event of an earthquake greater than the design earthquake.

COMMENTARY SECTION 6:

C6.0 NOTATION:

k_{db} = post-elastic stiffness of dissipators plus elastic stiffness of bearings

k_{pb} = elastic stiffness of piers plus bearings

Q_d = force due to dissipator at zero displacement ordinate

W = weight of superstructure

Ø = capacity reduction factor (as per ref C6.4)

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C6.1 The system of "base isolation" generally comprises two basic elements:

(a) The structure is supported on flexible mountings to isolate it from the greatest disturbing motions at the likely predominant earthquake ground motion frequencies, and

(b) sufficient extra damping is introduced into the system to reduce resonance effects and keep deflections within acceptable limits.

Flexible mountings include elastomeric and sliding or roller bearings. It should be noted that the properties of the bearings have a significant influence on the response of the structure and the forces imposed on the substructure. Information on the dynamic behaviour of elastomeric and sliding bearings is given elsewhere[C6.1]. Several types of mechanical devices have been developed by the Physics and Engineering Laboratory of the New Zealand Department of Scientific and Industrial Research to provide the extra damping required under (b) above through hysteretic energy dissipation.

Many bridges traditionally have had one basic element of a base isolation system, that is flexible mountings by means of elastomeric bearings. There may be advantages in terms of reduced response by incorporation of flexible mountings in an otherwise monolithic structure, although this will only be beneficial where the predominant earthquake ground motion frequencies are in the short period range. The addition of mechanical energy dissipating devices to a bridge on flexible mountings may have the advantage of reducing resonance effects and keeping displacements within acceptable limits.

The following are bridge applications where incorporation of energy dissipating devices in bridges is most likely to be effective:

(a) in regions of high seismicity;

(b) mounted on a stiff substructure;

(c) mounted on a substructure desired to remain elastic.

The corollary is that energy dissipating devices are unlikely to be effective and may even be a disadvantage in regions of low seismicity or where mounted on a flexible or flexurally yielding substructure. It is therefore expected that the base isolation system will be used most frequently for structures in seismic Zone A.

The main potential for economic advantage lies in:

(i) Possible savings in abutment separation requirements and joint details as a result of reduced superstructure deflections;

(ii) redistribution of seismic forces on the substructure; for example control of seismic forces through energy dissipating devices at strong abutments rather than by ductile yielding of piers;

(iii) use of non-ductile forms or components;

(iv) greater damage control.

C6.2 Detailed information on the design, development and testing of mechanical energy dissipating devices developed to date is given in ref C6.1.

Design requirements for lead/rubber devices specific to bridges include allowance for lengthening and shortening effects such as temperature variations. Procedure adopted in the past[C6.1] has been:

(a) The displacement of the superstructure at "design earthquake" loading, and corresponding shear deformation across the lead/rubber devices, is estimated on the basis of design charts;

(b) the thickness of bearing is chosen so that the shear strain at "design earthquake" loading is approximately 0.5;

(c) the size of bearing is selected after design for allowable total shear strains under combinations of dead, live and overload, wind and temperature[C6.2], with an allowance for reduction in area of the braring equal to the area of the lead cylinder;

(d) the diameter of the lead plug is estimated from the effective yielding shear stress evident in test results[C6.1] to give the desired strength at the zero displacement ordinate.

It should be noted that the desirability of thick bearings, for increased horizontal flexibility under seismic loading, may conflict with the need for sufficient vertical stiffness to keep vertical vibration under live load within the required limits for liveliness. Some compromise between these two objectives may be necessary. It is anticipated that the addition of a lead plug to a thick rubber bearing will increase the vertical stiffness and reduce any liveliness problems, but no test information is available as yet to confirm this.

Test evidence indicates that the lead/rubber device will "creep" at load rates corresponding to ambient temperature variations and transmit considerably lower forces, approximately 50% than those at earthquake load rates.

C6.3 It is important that consideration be given to the likely earthquake ground motions at the site of the bridge. Where conditions are such that predominant frequencies of the ground motion are likely to be in the long period range of structures, for example where the structure is sited on deep, flexible alluvium or where the critical earthquake event may occur at a considerable distance away from the structure, a flexible mounting system may detrimentally affect the response of the structure[C6.3]. In such circumstances the structure is likely to be better off with energy dissipating devices than without them because of the extra damping, but as a design approach a base isolation system should not be adopted in this case.

Suitable design earthquakes may be regarded as those which have response spectra characteristics similar to the elastic design spectra specified in Section 2 of these recommendations, except that special consideration must be given if local site conditions could promote long period ground motions as discussed above.

C6.4 In suitable applications this requirement may be achieved with significant construction cost savings, particularly in Zones A or B but unlikely in Zone C. That is, the reduction in design forces on members of the substructure more than compensates for the extra cost of the devices and associated details. The extent to which the degree of protection is increased above the minimum specified in this section, if at all, to reduce the anticipated frequency of earthquake induced damage should be resolved with regard to the client's wishes.

Assessment of forces on substructure members may be made for common types of bridge using available design charts[C6.1]. For unusual or major bridges, a dynamic time-history analysis using realistic energy dissipator characteristics will usually still be required. The design charts were prepared, on the basis of parameter studies, for structures with and without energy dissipators where the substructure is to remain elastic. These charts are presented in ref C6.1 and cover the following cases:

(a) Elastomeric bearings only at both abutment and pier;

(b) energy dissipators at abutment only;

(c) energy dissipators at pier only;

(d) energy dissipators at both abutment and pier.

Earthquake acceleration records used are El Centro 1940 N-S, artificial

Bl and Parkfield. The charts may be used to assess either longitudinal or transverse response, or if desired response along an axis inclined to the principal axes.

As an example, a bridge structure with energy dissipators located only at abutments and elastic restraint at the piers is illustrated in fig. C6.1. Figs C6.2 and C6.3 are design charts for this case where the abutment is rigid, the energy dissipator strength $Q_d = 0.05W$, and for the El Centro 1940 N-S and Bl earthquakes respectively. The procedure for use of each chart is as follows:

(i) calculate weight of superstructure, W

(ii) calculate combined stiffness of dissipator plus elastomeric bearings at abutment, k_{db}, and determine k_{db}/W /mm

(iii) calculate stiffness of pier plus elastomeric bearings (or pier alone where superstructure is built-in to pier), k_{pb}, and determine k_{pb}/W /mm

(iv) from top half of chart, determine intersection of k_{db}/W line and k_{pb}/W curve to give force on abutment on vertical axis and superstructure displacement on horizontal axis

(v) determine force on pier by either

(1) multiply superstructure displacement derived from (iv) above by the calculated pier stiffness, k_{pb}, or

(2) from bottom half of chart, determine intersection of k_{pb}/W line and k_{db}/W curve.

It is proposed that charts similar to figs C6.2 and C6.3 will be produced based on the design spectra in Section 2.

C6.5 This requirement is regarded as sound engineering practice in view of the uncertainties in modelling and analysis of the structure and in the characteristics of ground shaking. However, it is recognised that this will not always be possible, particularly where non-ductile structural forms or elements are used. In general, where ductility can be sustained, the anticipated lower ductility demand on structures incorporating energy dissipating devices means that simplified detailing procedures appropriate for structures of limited ductility would be satisfactory. The required controlled post-yield behaviour may generally be achieved by provision of suitable margins of strength between ductile and non-ductile members and by attention to detailing, but without full capacity design procedures. For example, where forces in the sub-structure are calculated using design charts[C6.1] or from dynamic analysis, and where it is desired that the structure remain elastic up to "design earthquake" intensity, suitable provisions are:

(a) substructure members capable of ductile flexural yielding are to be designed for a probable flexural strength (based on a capacity reduction factor, ϕ, of 1.0 and yield strength of reinforcing steel of say, 1.15 times the minimum specified) equal to the calculated "design earthquake" moment;

(b) non-ductile substructure members, or members in which damage is unacceptable because of inaccessibility for inspection and repair, or all members in shear, are to be designed for a dependable strength (based on appropriate value of ϕ[C6.4] and minimum specified material strengths) equal to the force calculated in that member at the "design earthquake";

(c) the separation details between superstructure and abutment are to allow for a deflection at least of 1.5 times the values calculated at the "design earthquake";

(d) special reinforcement requirements in NZS 3101[C6.4] for confinement of concrete in bridge piers need not be complied with. However, good practice should be followed in the detailing of the transverse reinforcement to enhance ductility in the potential plastic hinge zones. The provisions for design of shear and confinement reinforcement for structures of limited ductility in Chapter 14 of NZS 3101[C6.4] or Section 7 of these recommendations, provide a guide but may be conservative.

(e) Care should be taken in detailing to ensure the integrity of the structure during earthquake shaking. Satisfactory seating lengths or alternatively positive horizontal linkages should be provided between adjacent sections of superstructure at supports and hinges and between superstructures and their supporting abutments.

C6.6 REFERENCES:

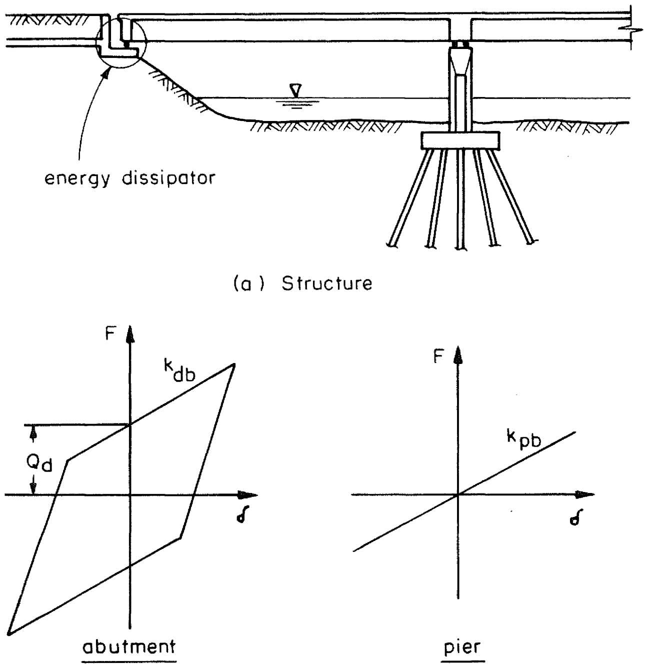
C6.1 Park, R. and Blakeley, R.W.G., "Seismic Design of Bridges", Summary Volume 3, Road Research Unit Structures Committee, New Zealand National Roads Board, Wellington, October 1978, 150 pp.

C6.2 ——, "Highway Bridge Design Brief", Ministry of Works and Development, Civil Division Publication, CDP 701/D, Wellington, New Zealand, September 1978.

C6.3 Priestley, M.J.N. and Stockwell, M.J., "Seismic Design of South

Brighton Overbridge - A Decision against Mechanical Energy Dissipators", Bulletin of the New Zealand National Society for Earthquake Engineering, Vol 11, No 2, June 1978, pp.110-120.

C6.4 ——,"New Zealand Standard Code of Practice for the Design of Concrete Structures", NZS 3101, Standards Association of New Zealand, Wellington, to be published in 1980.



(b) Force - Deflection Characteristics

FIG. C6.1: BRIDGE WITH ENERGY DISSIPATORS AT ABUTMENT ONLY.

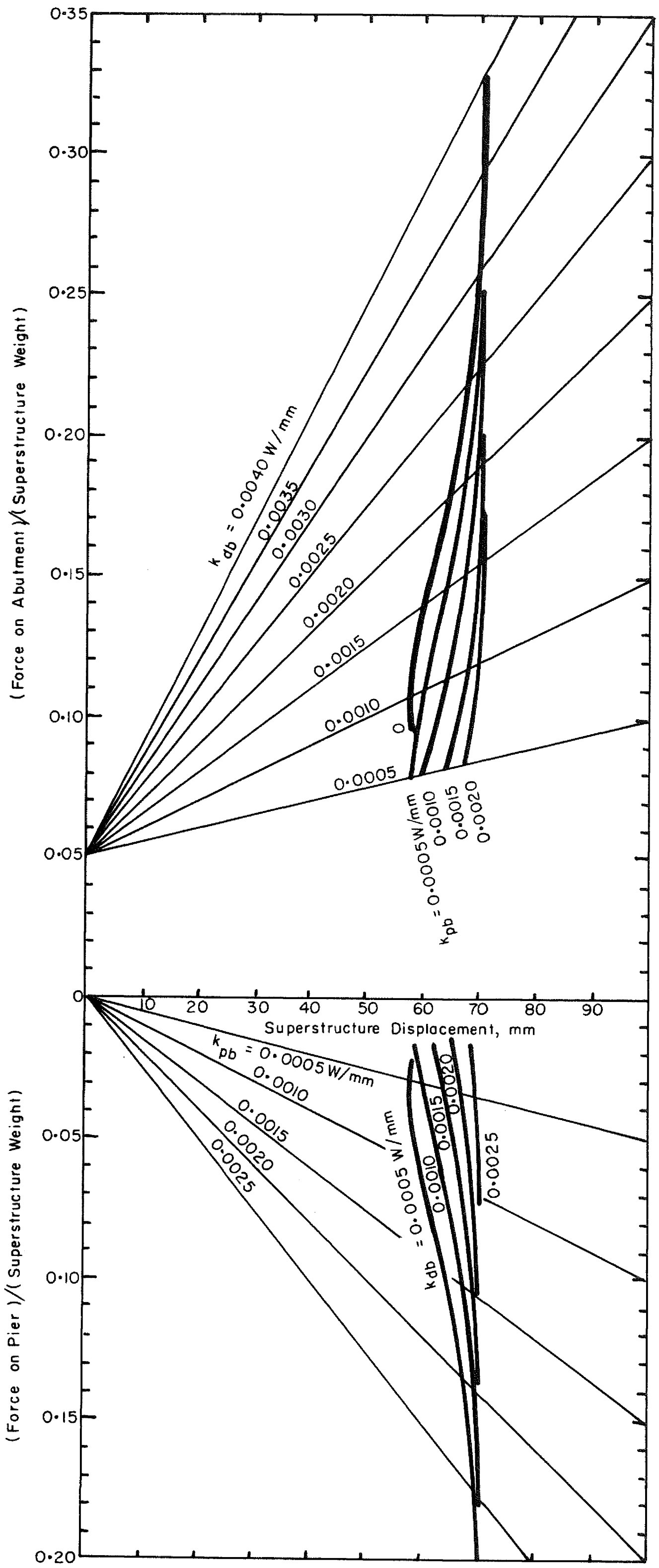


FIG. C6.2: ENERGY DISSIPATORS ON RIGID ABUTMENT, Q_d = 0.05W, EL CENTRO 1940 N–S.

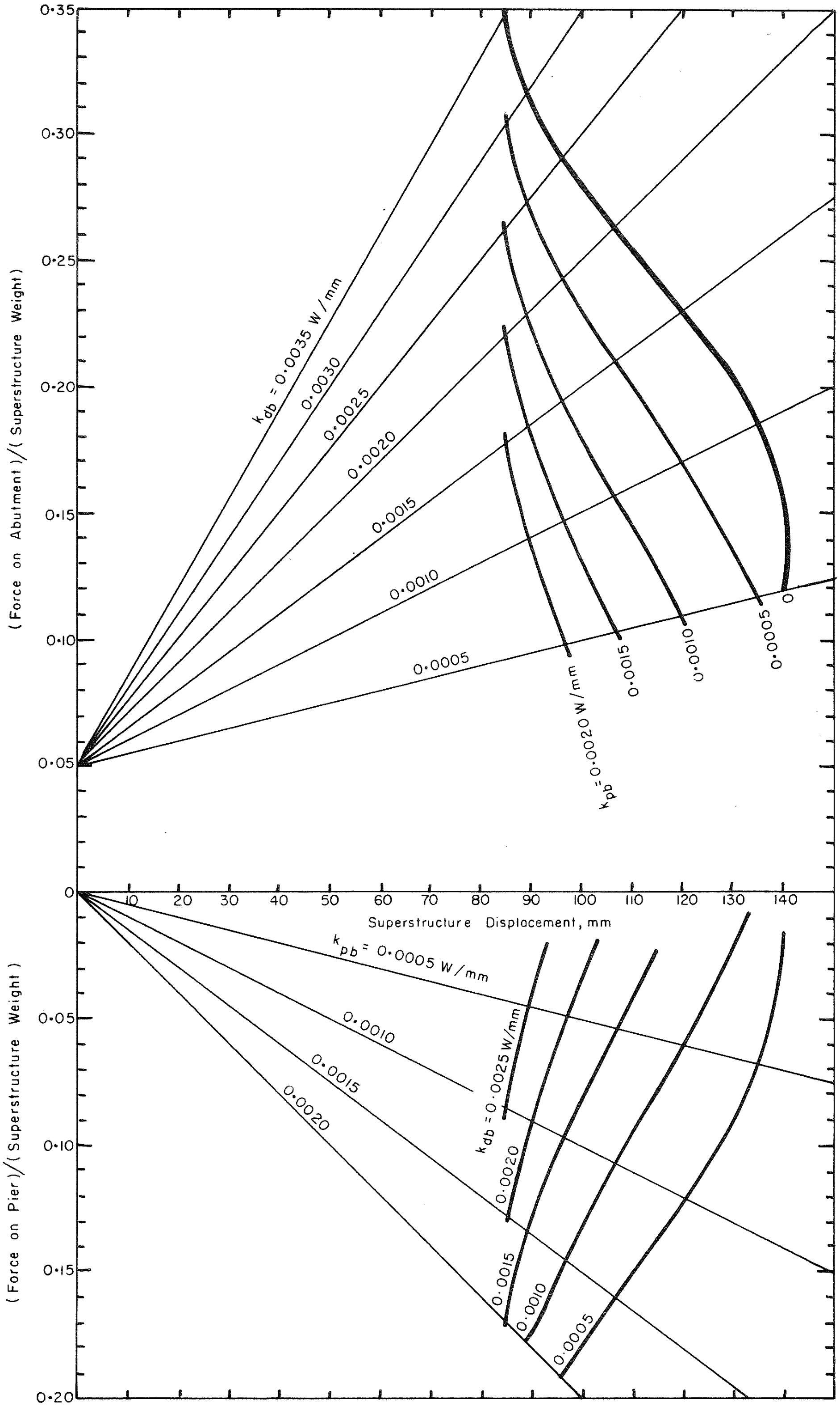


FIG. C6.3: ENERGY DISSIPATORS ON RIGID ABUTMENT, Q_d = 0.05W, B1