Abridgment

Earthquake Precursers and Potential Damage in the United States

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ABSTRACT

FHWA has issued earthquake design guidelines for new structures and for retrofitting. These guidelines follow the recent work product, published in October 1981, of the study done by the Applied Technology Council. Effective March 1, 1983, AASHTO has similarly adopted these criteria. Because this represents an area of design with few successful precedents and these guidelines are intended to encourage innovative thinking, this discussion will cover the following subject areas: (a) an introduction to the seismic design problem encompassing some of the fundamentals of what is known about earthquakes and their prediction, (b) examples of how structures are affected by mild and medium earthquakes, (c) the controlled base isolation concept, and (d) some of the design principles necessary for successful expansion joint and bearing performance during a typical earthquake. Some of the new tools and concepts that could be useful in seismic design are described together with their performance criteria and the testing accomplished to date to verify their performance along with design parameters for their use.

In the past there was, unfortunately, a lack of serious interest in seismic design by owners of our eastern highway network partly because of attendant costs but primarily because of the belief that earthquakes pose no threat to these structures. Comparatively high levels of ground shaking can be expected in 15 eastern states and Puerto Rico, and this situation is aggravated by the previous lack of emphasis on seismic design. Fortunately certain specific structural details can easily be modified especially at bearings and expansion joints, which have proven extremely vulnerable to damage in earthquakes. This discussion will be useful if it creates an awareness of the potential hazards and the catastrophic effects that can occur to essential lifeline structures that must remain operational at all costs during and after a strong earthquake.

SEISMIC EFFECTS ON BEARINGS

Regardless of their magnitude, intensity, or duration, in all earthquakes extensive damage occurs to bearings. Bolt pullout gives clear evidence of the need for strong uplift resistance to upward jerking vertical pullout stresses, a performance capability that will be described hereafter in the discussion of an improved type of bearing that incorporates a trailer hitch concept of uplift restraint. The embedment strength as well as the width and the length of the bearing seats need to be improved. It is now known that many popular bearing concepts are totally inadequate for seismic design.

SEISMIC DESIGN COMPONENTS AND REFINEMENTS

For the last 3 years, the authors of this report have been meeting regularly as a design task group to study what is known about the effects of earthquakes on structures and what can be done in terms of design concept, whether it be the classical or the controlled base isolation concept, to improve on the seismic performance of bridges and structures.

BONAFY--A STRUCTURAL ELASTOMER

The seismic design components described herein use a material known as "Bonafy." Bonafy is an internationally trademarked name for a specially developed structural elastomer in the polyether urethane family. A 50,000 psi material in compression, it is, however, only being loaded as a bearing component to 5,000 psi, which gives it a 900 percent safety factor. A similar material is used as a draft gear to take end-to-end slamming effects between adjacent cars in railroad operations. Bonafy has tremendous impact toughness and high abrasive resistance. It has been used successfully for the past 13 years without a single failure as the load bearing and rotational element in the shear inhibited disc bearing.

It was therefore believed that no known structural elastomeric material was better suited than Bonafy to resist the dynamic multidirectional impact forces of an earthquake. A new family of hardware and refinements in bearings have been developed for the needs of seismic design. For conventional earthquake design the new requirements for bearing systems, and therefore structural supports, are high horizontal force designs; bearings, which can take rotation during uplift, to accommodate uplift forces; special bearing guiding systems that allow rotation in plan; flexible guides that allow for some degree of self-aligning as well as equalization of forces between bearings during seismic conditions; special limit stop buffers and displacement control devices; and special connector cables that allow movement while absorbing energy during seismic events. The new "controlled base isolation" concept, which involves using bearings and displacement control devices, and the test results on these devices will also be discussed.

Uplift Restraint

Uplift bearings, such as the modified shear restriction mechanism shown in Figure 1, which acts like a vertical trailer hitch coupling to accommodate the forces, have been designed to simultaneously accommodate uplift and rotation during seismic conditions. Early attempts to absorb uplift forces

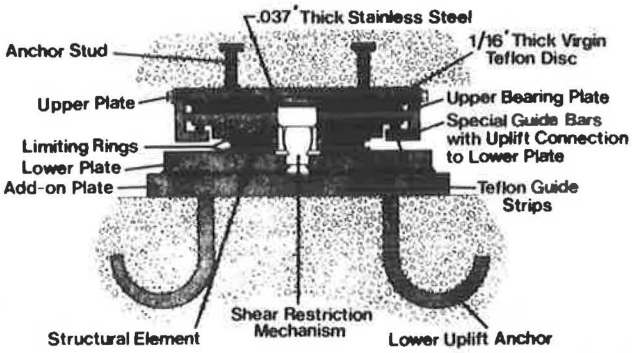

FIGURE 1 Special design bearing for high horizontal and uplift forces.

by simply attaching the bearing to the base plate did not allow rotation with the result that point loaded areas were established that created overload stresses. Simple clamp devices for uplift restraint are also unreliable because of high point stresses that develop during uplift and rotation combinations.

An example of bearing performance that is adequate for seismic needs is the Calgary Coliseum roof, which is shaped like a saddle and uses bearings designed for 400 kips vertical load, 400 kips uplift, 4 percent rotation, 12 in. of movement in all directions, and dynamic uplift--all conditions similar to those of an earthquake situation. Some of the steel plates in the bearings are approximately 8 in. thick. An interesting criterion for these bearings is that all steel was required to meet a notch toughness of 19 ft-lb at -40°F.

Self-Aligning Rotation in Plan

Another new seismic design feature that is also used in nonseismic applications is the self-aligning bearing or the rotation-in-plan concept. For unidirectional or guided bearings (Figure 2), a tetrafluoroethylene stainless steel slide plate is introduced between the disc and the steel plate to allow rotation in plan.

Flexible Guides

Flexible guides provide a way of incorporating Bonafy between the guide and the middle plate. This allows for a small amount of rotation in plan and also results in seismic force distribution between different bearings on the project. With conventional guides, one bearing must be designed to take the total horizontal force. Bearings such as this have been manufactured for the new Bear River Bridge in Nova Scotia, Canada, which is potentially a seismic area.

Limit Stops

Limit stop devices for seismic design vary in concept from a rubber tire to a sophisticated hydraulic ram system. Figure 3 shows a high-quality Bonafy elastomeric limit stop buffer.

Displacement Control Device

A more positive limit stop device is the displacement control device (DCD), shown in Figure 4, that is a single acting unit. This device can be used at both ends of a guided bearing or all four sides of a multidirectional bearing. The device can give simply a three-phase elastic effect or a three-phase elastic effect with energy absorption. The curve shown in Figure 5 illustrates the load deflection characteristics of the device as it becomes semiconfined and then confined like a pot bearing.

A DCD (Figure 6) is a series of Bonafy or other elastomeric discs in combination, a viscous material cell, and energy space all encapsulated in a steel shell riding on a steel rod assembly in a single acting device. Energy is also absorbed in the first seismic cycle.

The same DCD can be double acting. In that case,

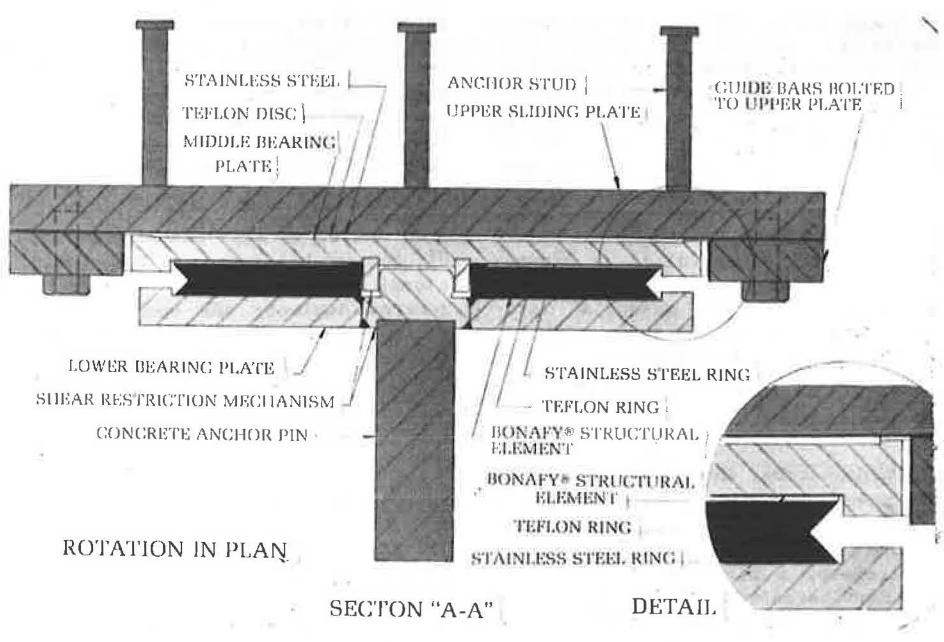

FIGURE 2 Self-aligning bearing.

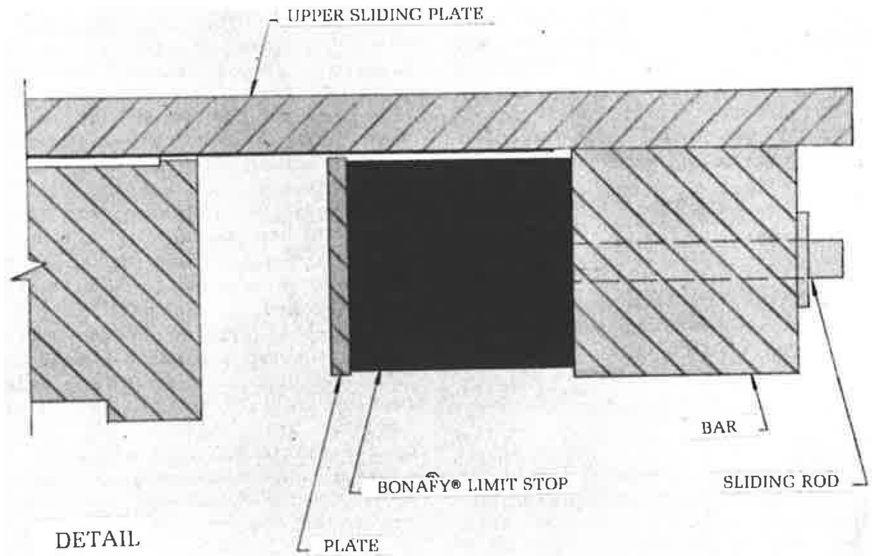

FIGURE 3 Bonafy® elastomer limit stop buffer.

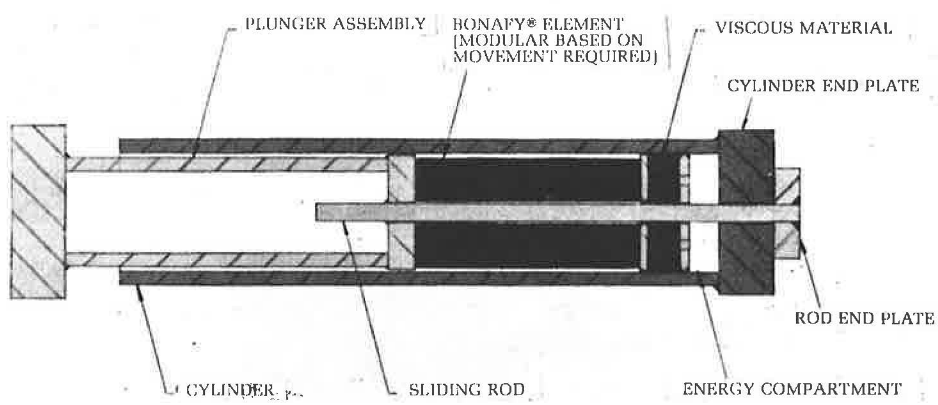

FIGURE 4 Single acting limit stop displacement control device.

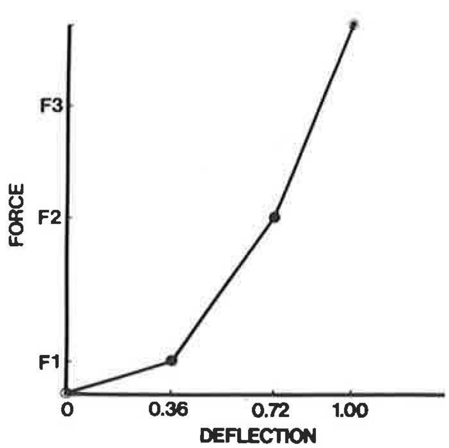

FIGURE 5 Typical load deflection curve.

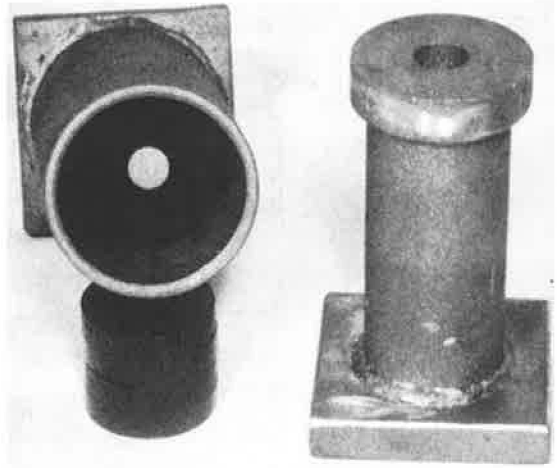

FIGURE 6 Displacement control device.

energy absorption is double acting and continues throughout the seismic forces and reduces movements substantially. This helps keep the seismic expansion joint design and cost minimized. This device functions in the following manner: the Bonafy discs are compressed as the DCD moves in each direction until the discs become fully confined when the energy absorption phase begins.

Restraint

The same DCD can be incorporated like a cable connector between spans or at abutments of new concrete or steel structures. It can also be used in retrofit situations.

Controlled Base Isolation

The controlled base isolation earthquake protection concept involves a conventional disc bearing that sits on a slip plane. The slip plane consists of a stainless steel-to-polytetrafluoroethylene sliding surface at the bearing seat location (Figure 7). A standard shear inhibited disc bearing system is connected to a slip plane by DCDs that are designed to perform at a predetermined earthquake force. Before seismic events, the bearing is independent of the slip plane and functions normally. During earthquake movements, DCDs, which also act as energy dissipators, control the translation of the bridge deck in relation to that of the piers and abutments.

Displacement Control Device

The key element in this earthquake protection concept is the DCD. The principal functions of this device (Figure 8) are to allow movement of the structure during seismic forces, dissipate the energy of those forces, control and reduce the displacement of the structure, and restore the structure to its original pre-earthquake position.

The entire DCD assembly is connected to the superstructure and bearing seat by universal hinge connectors that allow seismic movement in any direction. A key element is the hinge connection that works like a ball and socket system to allow multidirectional movement. Uplift forces can be controlled through the use of a DCD coupled to the bearing seat applied in the vertical direction. The use of the two preloaded DCDs coupled to the bearing seat and structure at 90°F provides earthquake protection regardless of the direction of seismic forces. The residual compression force generation of the elastomers will dissipate the seismic energy, control the displacement, and apply a restoring force to the structure. To conduct further tests on an actual bearing system that uses these displacement control devices, a new test machine has been designed to verify performance. This machine has a 4,000-kip vertical capacity with a 1,200-kip capacity in the horizontal plane.

On the basis of the testing done to date, DCD selection tables have been formalized. Through the use of seismic design criteria the engineer calculates the earthquake force that is anticipated. With this force in mind, the designer can refer to Table 1 and select the outside diameter and area of the DCD cylinder. Along with the forces, the engineer must calculate the anticipated seismic displacement

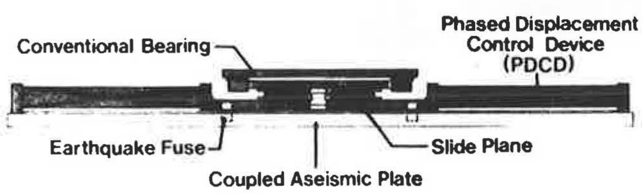

FIGURE 7 Controlled base isolation concept.

TABLE 1 Earthquake Force Versus Outside Diameter and Area of DCD Cylinder

Earthquake Force		Displacement Control Device			
		Outside Diameter		Area	
Kips	kN	in.	mm	in.^{2}	m^2
35	150	4	101	7	0.004
100	440	6	152	20	0.013
250	1110	10	254	51	0.033
550	2440	14	356	114	0.073
1,000	4440	20	508	230	0.148
1,500	6670	24	610	332	0.214
2,000	8890	27	686	410	0.264

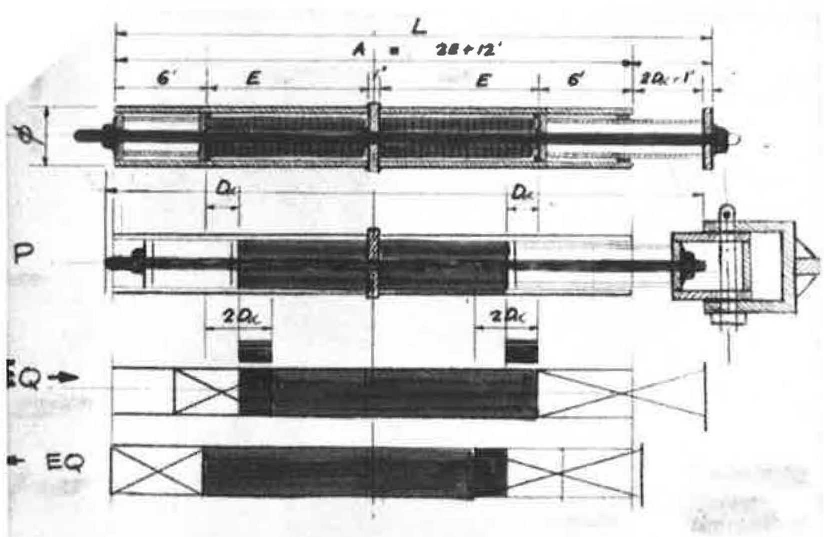

FIGURE 8 Schematic of displacement control device.

TABLE 2 Earthquake Displacement (N) Versus DCD Displacement (d), Length (L), and Elastomer Thickness

		Displacement Control Device									
N		d		L		SK 1		SK 2		SK 3	
in.	mm	in.	mm	in.	mm	KSI/in.	MPa/mm	KSI/in.	MPa/mm	KSI/in.	MPa/mm
2	51	1	25	26	660	0.444	0.121	1.480	0.402	13.90	3.781
4	102	2	51	36	914	0.222	0.060	0.740	0.201	6.95	1.890
6	152	3	76	46	1168	0.148	0.040	0.493	0.134	4.63	1.259
10	254	5	127	66	1676	0.089	0.024	0.296	0.080	2.78	0.756
20	508	10	254	116	2946	0.044	0.012	0.148	0.040	1.39	0.378
30	762	15	381	166	4216	0.030	0.009	0.099	0.027	0.927	0.252
40	1018	20	508	216	5486	0.022	0.006	0.074	0.020	0.695	0.189

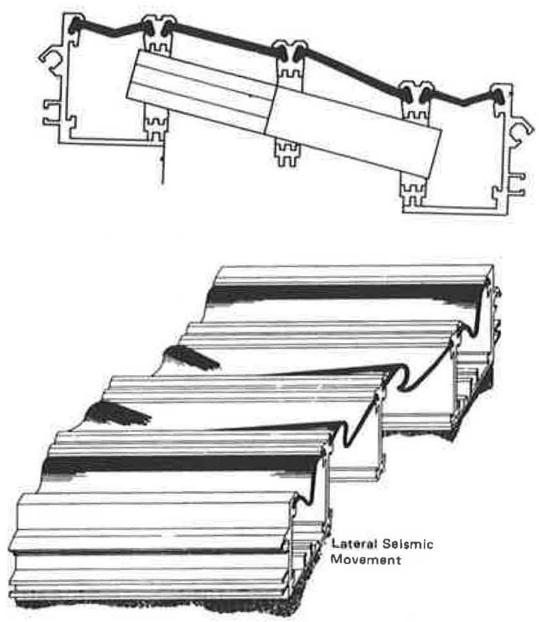

FIGURE 9 Expansion joint.

of the structure. The DCD is designed to reduce the seismic displacement by a factor of 2. Table 2 gives the engineer the new displacement value and the length of the device. This table also gives the three different stiffness stress factors SK 1, 2, and 3. These factors will give the designer the three phases of the force displacement curve. With these steps completed, the engineer has the dimensions of the DCD, and the earthquake protection system can be designed into the structure.

Seismic Expansion Joint

Figure 9 shows an expansion joint, with large movement potential, that has been specially designed to accommodate multidirectional seismic movements from virtually any direction in addition to its normal stroke of thermal dilation.

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