Damping and its importance to structure

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Abstract

The bridge of Zeceva Draga is currently being built in Croatia. Its total length is 940.8 m. It is in a horizontal curve. Its spans are 2x40+16x50+1x40. The columns are very tall; the tallest of them is 53 m high. Because the columns are extremely high, and the structure itself has a longer period, the application of elastomeric bearings on the bridge is not significant. Therefore, the bridge was calculated with the action of hydraulic dampers at the ends of the span structure towards the abutments. Time history analysis was calculated for accelerograms of magnitudes 5.5, 6, 6.5 and 7 (Richter scale) with distances of 0 and 15 km from the epicentre, based on earthquakes occurring in Petrovac, in April 1979, with a magnitude of 6.8 and Ulcinj, in April 1979, with a magnitude of 5.3, in the region of the Adriatic coast. The damper was modelled using the Calvin's model. Since it is not a classical damping, the damping of the structure was calculated separately, and then the influence of the damper was added. Damping of devices is modelled depending on velocity. The damping of devices itself significantly reduces the force. The rigidity of the damper is apparent and it was used to simulate the elastic behaviour of the device because of the hydraulic compressibility. In the laboratory of the Civil Engineering Faculty in Zagreb, the model with two spans was tested with and without dampers, in the longitudinal and transversal directions, and it was proved that dampers increase the damping of the system. The application of dampers is diverse, from silos, masts, towers, stands to bridges and factory chimneys.

Keywords: damping, damper, earthquake, dynamic analysis, bridge.

1 Introduction

The structures take on great quantity of energy generated by earthquakes. That energy can produce considerable deformations, even fracture of a structure. A structure must have capacity to dissipate that energy, either by permanent deformation or by dampers placed in the structure. The most frequently applied damper is one based on viscous fluids, or hydraulic dampers. Viscosity or internal friction is a friction force produced by rubbing a one fluid layer against the other while they are in motion. In such device a fluid is pushed by a piston from one into the other chamber. Viscous dampers are devices enabling displacements due to temperature changes, creepage and shrinking, without creation of significant force, but dissipating great quantities of energy during sudden occurrence of dynamic entrance of seismic energy. The devices enable more even inlet of energy into a structure and avoidance of energy accumulation.

2 Types of damping

Types of damping are: viscous and hysteretic damping. Viscous damping depends on frequency. Hysteretic damping assumes non-linear relations between stress - deformations. Some materials, such as structural steel, are almost ideally elastic up to the elasticity limit. With these materials, that type of dissipation can occur during stress much lower than the stress at the elasticity limit. It can be explained by concentration of stress and residual stresses. To conclude, damping lowers amplitude during vibration of structure. With viscous damping, the damping force is proportional to the speed. The damping force of Coulomb damping is constant. Solid damping or hysteretic damping is caused by internal friction when a solid is deformed. Its size is related to the amplitude of stress. Other types of damping are often replaced by viscous damping in order to linearize equations of motion which would facilitate its solving. However, it is not necessarily adequate way.

2.1 Viscous damping

For viscous damping we have force-velocity relation as in eqn (1):

$$F = c \cdot v^n \tag{1}$$

where F is force, c is damping constant and v velocity. Proportion between damping and critical damping for viscous dampers is 0,61. With viscous damping the curve representing relation between force – displacement has elliptic shape. The surface of the ellipse represents energy dissipated in a cycle. Dissipated energy is proportional to the square of the amplitude of motion.

2.2 Hysteretic damping

Solid damping, structural damping, or hysteretic damping are terms that determine internal damping. Energy dissipated in a cycle is independent of frequency for this type of damping.

$$F = k \cdot x \tag{2}$$

In eqn (2) F is force, k is constant of hysteretic damping and x is displacement. Hysteretic damping constant is a measure of hysteretic loop and a feature of material or structure. Energy dissipated per each cycle is not proportional to the square amplitude of motion. Significant damping type is Coulomb friction damping. It is also called constant damping, because the damping forces are independent of displacement.

3 Modelling of damping

It is difficult to determine damping properties, i.e. coefficients of damping matrices. It is impractical to determine coefficients of damping matrices directly from structure dimensions, size of structure elements and damping properties of materials used for the structure. For this reason damping is specified by numeric values for modal damping ratio**.** Damping matrix is essential for analysis of linear systems with non-classical damping or for analysis of non-linear structures. Classical damping is not applicable if we analyse a system consisting of several elements with considerably different damping values, for example structure-ground**.** Modal damping ratio of ground is different than structure damping and amounts 15-20%, and of structure 3-5%. Classical damping matrix be applied only when ground and structure are each considered separately. Damping matrix for complete system is constructed by direct connecting of damping for two sub-systems: structure and ground. Classical damping cannot be applied neither for structure with special dissipation devices nor with base isolators. Firstly, for such a system a damping matrix is calculated for the structure itself (without special devices) for damping ratio applicable to structures. Damping of dissipator is then added in order to get the matrix of complete system.

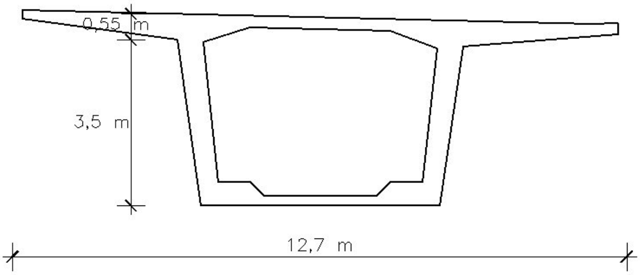

Figure 1: Model of Zeceve Drage bridge.

4 Cross section of bridge

Zeceve Drage Bridge is 940,8m long. It is situated in a horizontal curve. The height difference between left and right abutment is approximately 23m. Span structure is a box girder 12,5m wide and 4 m high. The area of cross section above the support is 10.2 m^2, and in the field it is 9.4m^2 . The piers have rectangular cross section at the top, which changes into hollow, with 30 cm thick wall, expanding to 50 cm at the bottom. The ground class is A. The bridge has 18 piers, the highest being approx. 53 m high. The spans are 50 m, except for the ones closer to the abutment, which are 40 cm. The bearings are pot type, because the greater earthquake force is expected. The effect of elastomer bearings is inconsiderable, due to specific features of the structure, namely its high piers. Dynamic analysis was conducted with mode damping of 0.05. The most specific type of dynamic load is earthquake load which results in non-linear behaviour of a structure.

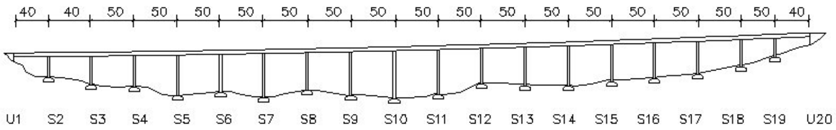

Figure 2: Longitudinal section of bridge.

5 Model of earthquake used for calculation

Selection and defining of representative accelerogram as a basis for designing the Zeceve Drage Bridge is extremely complex considering the type and intended purpose of the future project, its location and availability of collected data on destructive earthquakes in Croatia. Based on available instrument data and digitized accelerograms, two earthquakes were selected according to their magnitudes for the needs of location, namely: earthquake occurring at 6h 19 min a.m., on April 15, 1979, with magnitude M=6.8, and earthquake occurring at 2h 10 min a.m., on April 9, 1979, with magnitude M=5.3. Both earthquakes have originated in Montenegro coast, and were recorded at the following locations: earthquake of April 15, 1979, with magnitude M=6.8, on Petrovac location, with epicenter distance of 19.5 km, and earthquake of April 9, 1979, with magnitude M=5.3, on Ulcinj location, with epicenter distance of 17.5 km. The highest ground acceleration for magnitude 7 and epicentre distance of 0 km is 2.5 m/s2, and the lowest, for 5.5 M and 15 km epicentre distance, is 0.47 m/s^2. Time history analysis was preformed for past period of 1000 years. Calculation was made for synthetic time sequence of accelerations which, on the average, correspond to earthquakes with magnitudes 5.5, 6.5 and 7.0, and epicentre distances of 0 and 15 km. 10 m hypocentre depth was generally assumed. The following assumptions were applied for calculation of synthetic accelerograms: a) relation GZ300 (Prelogović et al. [5]) which connects maximum horizontal acceleration, hypocentral distance and earthquake magnitude, b) average Fourier's spectre corresponds to one which McGuire [6] described in parametric form, in relation to magnitude and distance of earthquake, c) no regularity of phase spectre accelerogram (random vibration), d) considerable earthquake duration can be foreseen as suggested by Trifunac and Brady [7], e) accelerogram envelope can be represented by adapted Berlage's function, f) the base has characteristics of main rock.

6 Calculation results of Zeceve Drage Bridge

Viscous dampers are designed at the ends of substructure near abutments. They are made in such a way to give the following features: stiffness and damping. Given rigidity is such to assume that 4% of total displacement of device is considered the elasticity limit. Damping of damper is defined by quotient of force as in eqn (1). Damping of structure itself is represented in modal form, namely by value 0.05 for concrete structures. Forces in section acting longitudinally to the bridge are observed at piers S8 – S13, because each has one fixed bearing in longitudinal direction.

Table 1: Moments and beam forces without damping.

Column	S8	S9	S10	S11	S12	S13
Force (kN)	1922	2474	1202	1099	1317	1957
Bending moment (kNm)	78242	92996	55473	50150	59726	79759

Table 2: Moments and beam forces with modal damping.

Column	S8	S9	S10	S11	S12	S13
Force (kN)	1507	1936	889	752	1002	1549
Moment (kNm)	61655	73109	42900	38230	46626	62864

Table 3: Moments and beam forces with damping from damper and modal damping.

Column	S8	S9	S10	S11	S12	S13
Force (kN)	1015	1392	602	472	743	1091
Moment (kNm)	41610	52665	26537	20555	34947	44275

Table 4: Moments and beam forces with damping from damper (with stiffness) and modal damping.

Column	S8	S9	S10	S11	S12	S13
Force (kN)	808	1036	455	359	571	808
Moment (kNm)	33057	39122	21956	18250	26570	32791

Table 5: Beam forces (comparison).

Column	S8	S9	S10	S11	S12	S13
No damping	1922	2474	1202	1099	1317	1957
Damping 0,05	1507	1936	889	752	1002	1549
Damper 1500 kN	1017	1510	632	498	799	1184
Damper 2000 kN	1015	1392	602	472	743	1091
Damper 3000 kN	855	1186	552	424	664	928

7 Laboratory testing

Test of bridge model with dampers of longitudinal and transversal direction were conducted in laboratory of Civil Engineering Faculty in Zagreb. The bridge is made of steel, has two spans, each of 400 mm. The superstructure is constructed with 60 mm wide and 5 mm high steel plates; at its centre is supported by a pier, and at the ends by abutments. The pier is 130 mm high, with dimensions 20 x 20 mm. The bearings made of elastomer have dimensions 10 x 10 x 5 mm. The hammer, which is equipped with accelerator, incites the bridge, while another accelerator placed at the bridge superstructure above the pier measures the structure incitement response. The results were compared with data obtained by calculations. The experiments confirmed results obtained by calculations.

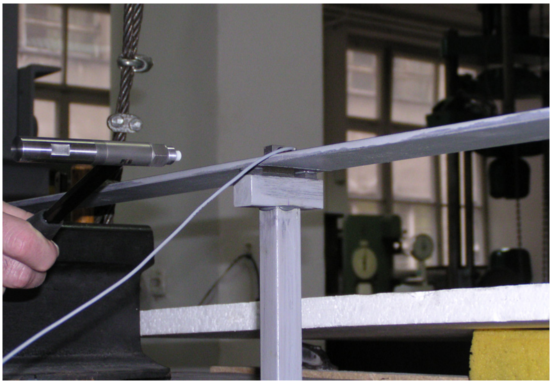

Figure 3: Incitement of the bridge model with hammer.

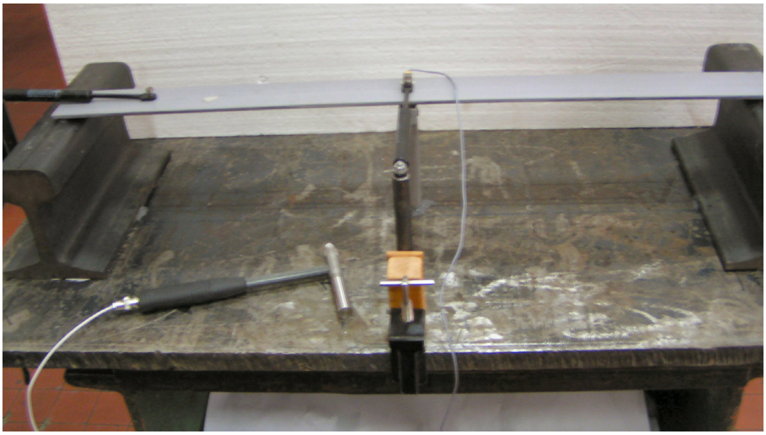

Figure 4: Model of bridge with dampers.

Table 6: Damping of bridge model.

Axis	Without damper	With damper (50N)
x	9.8%	14.89%
y	10.6%	12.47%

8 Conclusion

Dampers are important for several reasons. Their stiffness affects a period which, because of piers, is very long (4.86 seconds), and they also reduce maximum displacement. This paper examines their greatest importance, namely reduction of force in the piers by damping, during which process the piers remain in elastic area. Damping effect to the structure is also considerable. The dampers dissipate energy so that less energy enters the structure. By their installation, the energy entering a structure is more evenly distributed. Therefore, they have recently become widely applied.

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