SEISMIC PERFORMANCE OF BRIDGE HIGHWAYS DURING THE JAN. 17, 1994 NORTHRIDGE EARTHQUAKE RELATED WITH BRIDGE RETROFITTING

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1. EARTHQUAKE DESCRIPTION

A magnitude 6.8 (On the Ritcher scale), 8 seconds earthquake (in the epicentral region) rocked violently the northern San Fernando Valley- southern California with two separated jolts, on Jan. 17, 1994. The epicenter was located 17 Km beneath the ground approx. and 1.6 Km from the center of Northridge, a highly urbanized area. Considering peak horizontal ground accelerations greater than 0.05g the strong ground shaking latest 15~20 seconds at and near the epicenter with a predominant period of 0.25 ~0.4 sec.

2. SEISMOLOGICAL AND GEOLOGICAL CONSIDERATIONS

The soil in the San Fernando Valley is composed by loosely compacted alluvial sand, silt and gravel with depths up to few meters. Los Angeles Basin region is characterized by unconsolidated to moderately consolidated late quaternary sedimentary deposits in which the seismic wave velocity decreases while the amplitude (wave length) increases. The shear wave velocity within these sedimentary deposits varies from 290 m/sec to 540 m/sec in the San Fernando-Antelope valleys.

3. ANALYSIS OF DAMAGES TO FREEWAY/HIGHWAY BRIDGE STRUCTURES CAUSED BY THE JAN. 17,1994 NORTHRIDGE EARTHQUAKE

The 6.8 magnitude, Jan. 17,1994 Northridge Earthquake caused the collapse of seven key bridge structures on heavily traveled freeways. It was the result of failures at columns that were designed prior to the Sylmar quake in 1971. Other types of damages reported on 51 bridges included spalling and cracking of concrete abutments, spalling of cover concrete, settlement of bridge approaches and tipping or displacement of both steel and neoprene-type bearings. Site effects had a fairly variation in the intensity of ground shaking even within small areas. Among the principal causes of damage to bridge structures during the 1994 Northridge Earthquake are: High accelerations with periods that may produce resonance to bridges, inadequacies in the distribution of rigidity on columns, deficiences in the structural design of hinge joints as well as brittleness of the shortest columns which hinder them to bend like the taller columns in the same spans. The bending of tall columns caused that large earthquake forces had to be transferred to short columns which in turn were not properly designed to absorb such forces, as consequence of that these lost their bearing capacity under the combined shear and compressional loading and then shattered causing the fall of some overcrossings.

4. CASE CONSIDERED:
INTERSECTION OF THE GOLDEN STATE FREEWAY (I-5) WITH THE ANTELOPE VALLEY FREEWAY (ROUTE 14)

Near Santa Clarita (north of the San Fernando Valley), a bridge of the Golden State Freeway (Interstate 5), one of the state's major north-south arteries collapsed at its junction with the Antelope Valley Freeway Overpass (State Route 14), about 11 km. north of the epicenter. Four spans of two fly-over ramps slipped off their bearings at abutments and caused the rupture of the mentioned overpass. One span collapsed onto northbound I-5 and the others three collapsed onto southbound I-5.

4.1 Interstate 5 / Route 14 Interchange - Separation and Overhead

At Southbound 14 ramp connector onto southbound I-5

Characteristics of the structural system

- 492 m length, 15 m width and 650 m radius curved structure.
- 10 spans along five continuous segments connected by hinge restrainers, cast in place, five cell (1.7 m deep) concrete box girder. The spans were supported by 38 cm length seats at the intermediate hinges. Each of the 3 restrainers placed across the hinge joints were composed by 4 steel cables confined within a steel pipe extended across the two adjacent span segments through a concrete diaphragm wall, see Fig. 1.
- Abutments (seat type) and single columns were on spread footings or piled footings. The foundation were on loosely compacted alluvial sand with gravel. The structure had not been fully completed by the time the 1971 Sylmar Earthquake did occurr. It was completed on 1972 with restrainers at hinge locations but abutments remained without restraining devices.

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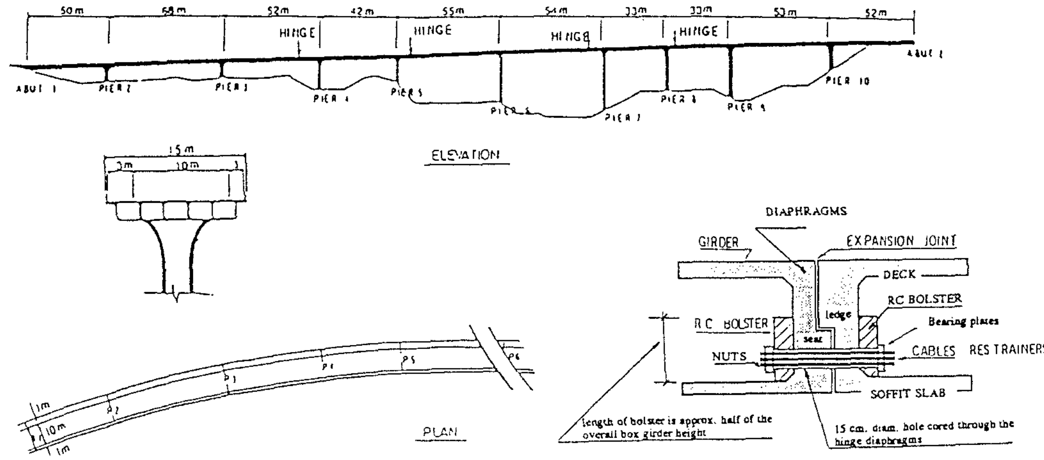

Fig. 1 Geometrical details of the Interstate-5 /Route 14 Interchange. Separation and Overhead.

Failure mechanism

- The failure mechanism that seems to be occurred on this bridge may be identified by the unability of short columns to bend enough in order to absorb the larger shear forces transmitted by longer columns. On the other way, the restrainers at hinge joints could not withstand the strong ondulation of the superstructure produced by the vertical motion that seemed to lift the bridge decks enough to produce the come down of them and simultaneously the swing of bridge columns, the combination of these simultaneous effects probably caused that the whole structure mushroomed and then induced the fall of the next span.
- Three spans dropped between pier 3 and the nearest abutment probably when a 13 mm thick steel plate placed at a hinge support became loose permiting that the restrainers had been pulled out by earthquake forces which exceeded their restraining capacity.
  Columns seems to be punched up through the superstructure and immediately after to the next span which fell off the hinge on which sits, also a 6m height column (bent 2) nearest the abutment and pier 3 seems to be crushed by the fall of a span, # 18 reinforcing column bars sprained. Very tall flexible columns of this interchange sustained relative displacements atop them greater than 38 cm affecting directly to hinge joints.

5. BRIDGE RETROFITTING AND CONCLUSIONS

The success of the retrofitting program for California's bridges is certainly in progress, however many considerations for improving the retrofitting criteria have yet to be ascertained such as :

- The number of cable restrainers should be increased in order to permit more capacity of deformation and simultaneously the anchorage of restrainers should be upgraded.
- Much research work for the structural behavior of connection details between footing and columns needs to be done in order to provide more ductility at the foundation-column connections.
- Further study related on the distribution of earthquake forces on columns that support skew bridges needs also to be conducted.
- Design approaches must require bridges to be designed and detailed to ensure predictable post elastic behavior trying to keep a balanced interrelation between the dissipation of earthquake energy by columns and restraining devices. For bridges of complex geometry in complex site conditions would result expensive in some degree to design through totally elastic response. It leads to consider the inelastic behavior for such cases.
- Improvements in the lateral confinement of columns and provision of steel jackets on them have permitted to increase their ductility and strength, however much research is also needed about the effects of column splices in the develop of large tensile forces and ductility.
- Hysteretical behaviour in columns subjected to the simultaneous combination of horizontal and vertical motions should be considered in the seismic analysis of bridges, some recent studies that considered the effect of vertical motion on bridge columns showed that the hysteresis loops are very unstable and asymmetric when the up-down motion is taken into account, fluctuations in the stiffness of columns has resulted in appreciable variations in the amount of lateral force carried by the columns.