

NOTES ON BRIDGES AND EARTHQUAKES

J. B. Wilson, B.E., B.Sc., M.Inst. C.E., M.N.Z.Inst.E.
(Bridge Engineer N.Z. Govt. Railways)

Historical

Following the disastrous Napier earthquake in New Zealand (1931) seismic resistant construction has been a factor in bridge design in New Zealand. An early Government instruction is as follows; "Wherever possible the structures should be made monolithic, and where this is not possible all parts of the structure should be well tied together. Piers should be designed to resist an acceleration of one-tenth the weight of the super-structure". (1)

In 1956 the Ministry of Works issued a "Bridge Manual" which states "All bridges and parts of bridges shall be designed and constructed to withstand earthquake forces. The effect of earthquake shall be considered equivalent to a continuously applied horizontal force equal to one-tenth of the assumed weight of the structure which can be dependent on any member". (2)

Currently, the trend is to apply to bridge design seismic provisions contained in the New Zealand Model Building By-law (3). This code divides New Zealand into three seismic zones and includes a seismic "spectrum". It also requires (clause 8.36.1.4) an increase of fifty per cent in the equivalent statical seismic co-efficient for inverted pendulum type structures which include numerous bridges. The resulting equivalent statical seismic co-efficient may thus rise as high as one quarter gravity instead of the earlier value of one-tenth.

Typical N.Z. practice

A detailed account of past N.Z. practice in the design of concrete railway bridges is a paper by C.W.O. Turner (4), where it is stated, Pg. 312, "Earthquake forces on the unloaded structure are computed for a horizontal acceleration of one-tenth gravity".

It is of interest to note that four of the bridges described in reference (4) (at Slaty, Newman, Stable and Redmond; figures 10 and 11 also refer), are situated in the Buller Gorge, Westland, and are in the group of bridges nearest to the epicentre of the recent Inangahua earthquake. All four bridges show no signs of damage due to the earthquake.

The need for ductility was beginning to be appreciated - Appendix B Ref. (4).

Comparable Japanese practice and design criteria may be found in a more recent paper by Y Matsumoto (5) "Earthquake force - one fifth of the dead weight of super-structure (equivalent lateral force method)" and, "To make the structure aseismic the ends of the columns were closely reinforced with $\frac{3}{8}$ inch ties at 4 inch spacing".

Buildings comparison

In his paper to the Third World Conference on Earthquake Engineering (6) J. Koderia emphasises seismic resistance differences between bridges and buildings such as the absence of interconnected footings (for river crossings) and the influence of permanent displacements in adjacent soil masses under piers and at the ends of bridges.

It may be recalled that Tachu Naito of Japan, whose shear wall buildings fared well in the great Kanto earthquake of 1923, sought to regard a building as a ship in a sea of turbulent soil. Further the U.S. Uniform Building Code (7) states "All portions of structures shall be designed and constructed to act as an integral unit in resisting horizontal forces unless separated structurally by a distance sufficient to avoid contact under deflection from seismic action".

On the other hand, the three bridges seriously damaged in the recent Inangahua earthquake (8) may be regarded as an aggregation of individual structural elements tied together, and into adjacent banks at deck levels. Thus a seismic co-efficient applied to the weight of the ties (spans) may have little if any relevance to the strength needed in the span to pier connections, owing to movements of adjacent soil masses.

Bridging operational requirements

Seismic resisting priorities for a bridge subjected to a major shock include -

- (a) Loss of life is avoided
- (b) Spans remain on piers, in order to facilitate resumption of traffic.
- (c) Damage to bridge is an economic minimum.

A major quake affects a large area and will not pass unnoticed, which permits inspections of bridges to be made before traffic is resumed. The Pajaro bridge on the Southern Pacific railroad between Los Angeles and San Francisco spans not only the Pajaro river but also the well known San Andreas earthquake fault in the river channel at this locality. Provision for traffic safety is made by automatic warning devices which will cause the traffic signals to go to danger in the event of an earthquake (9).

It was fortunate indeed, that the spans of the Landing Bridge (8) remained on the piers after the recent Inangahua earthquake and it is estimated that had the spans and piers of this bridge collapsed into the river (as appeared likely) the time and cost for restoration of rail traffic to Westport for the entire railway line would have been doubled.

Practical seismic design (bridges)

A typical smaller river bridge that has been carefully designed for such factors as river flood and traffic braking loads may require no significant increase in costs of construction in order to provide adequate seismic resistance and in fact may call for little more than

careful detailing. This state of affairs may well have permitted two relevant bridging references from U.S. sources (10) and (11). "In regions where earthquakes may be anticipated, provision shall be made to accommodate lateral forces from earthquakes as follows: "Lateral force = one twentyfifth dead load of structure for structures founded on spread footings on material rated as less than 4 tons per square foot"; and etc. (Ref. 10)".

Further reference (11) states "In recent years no earthquake damage is recorded in the United States to bridges except drawbridges".

Larger structures may justify special treatment if in concrete, although a steel viaduct carefully designed for normal wind allowances will probably also be satisfactory for earthquakes. F. W. Furkert stated (12) regarding the behaviour of large steel railway viaducts in the Napier earthquake; "The viaducts were carefully examined shortly after the earthquake, and the damage was found to be less than had been anticipated ... This can be accounted for to some extent ... they had been designed ... to withstand a wind pressure of 50 lbs. per square foot on the unloaded structure ..." Also D. B. Gumensky states "The design of large suspension bridges is usually governed by wind loads but not earthquake forces". (Ref. 11.)

However, in the case of high long span concrete viaducts, a target seismic loading for economy is to arrange the lateral earthquake forces to be of comparable magnitude with those from wind, and therefore, little extra provision is required to accommodate the seismic effects (see below).

Seismic design principle

In seismic resistant building design "ductility" has become recognised as a vital requirement.

Similarly, it may be said in bridging that proper "RELATIVE STRENGTHS" between the various components of a bridge are essential for resistance to earthquake accelerations and displacements, and the latter may be even more important at times than the former. Just as a badly designed motor car may have engine power too great for the transmission (with consequent distressing breakdowns from time to time) so can a bridge have a bad arrangement of relative seismic strengths. The writer can recall a dramatic example which came to his notice over thirty years ago and which has been repeated since. A large municipal elevated water tank and tower failed in the U.S. in spite of survival of numerous surrounding sprinkler tanks and towers of relatively more flimsy construction. The end connections for the massive cross bracing rods of the elevated tank that failed had been attached by a shear pin through a gusset and had substandard edge distance, so that the brace pulled out without plastic deformation and the tank and tower collapsed totally. In all probability had the cross brace been of half the strength and with the same end connection the tank tower would have suffered no more than stretched cross bracing.

Japanese recommendations for the connection of spans to piers state (13) "We should rather attempt to prevent the falling of the girder by introducing some or other ingenious devices in the details of the support, by enlarging the bearing part or by linking the girder with the adjacent one".

Therefore, in addition to exercising the maximum practicable care with the foundations of the bridge one must visualise likely and possibly substantial movements, or attempted movements of the members of the bridge and allow for these if expedient, but above all arrange for proper relative strengths between members, thus avoiding "brittle failure" due to "weak links".

Emilio Rosenbleuth (Ref. 14) states "Ductility plays such an important role in the design and behaviour of buildings that connections deserve the most meticulous attention ... If there is a well defined weakest link in the structure it will be called to absorb an enormous amount of energy, indeed the entire energy of inelastic deformation, whether that link is a cold joint, a connection or a careless detail".

Conversely, it may be desirable and worthwhile to arrange deliberate "fuses" in a bridge i.e. some form of structural discontinuity where seismic energy may be deliberately absorbed and the rest of the bridge thereby protected from seismic overload. Currently, Canterbury University is examining the possibility of inserting a "plastic fuse" in tall concrete bridge piers, to give "ductility" for axial loads, and reduce and limit the earthquake effect on such bridges to economic advantage.

An example of "fusing" by bending moment discontinuity may be noted in the large continuous truss bridge which carries the Southern Pacific Railroad over the Pitt River arm of Shasta Reservoir U.S. The piers are about 360 feet high and "rock" on the base which explains why the stability of such high piers is only slightly affected by earthquakes that have proved destructive to other types of structures (15).

A further example of rocking piers is the continuous steel truss highway bridge on tall concrete piers over the Eel River California (16) which was designed for earthquakes as follows: "Superstructure and pier shafts designed for one twentyfifth weight of dead load acting as earthquake. Pier footings designed so that the resultant of all forces including earthquake will fall within the edge of the footing". This design basis may be compared with that for the Piers of the Pitt River bridge (15) - "Design the pier base with strength and stability for the usual lateral loads, such as wind and traction forces without any consideration of earthquake effects. Design the pier above the base for lateral earthquake forces of such intensity that the resultant is at the edge of the base".

The principle of relative strengths is inherent in the Japan Society of Civil Engineers dissertation (13) and it may be inferred from Kodera's paper (6) to the effect that, in spite of expected seismic displacements and inertial effects the relative strength of the bridge components require to be arranged so that the span to pier connections will not fail, and the deck may act as an unbroken strut from end to end of the bridge.

In the Napier earthquake (N.Z. 1931) the Westshore concrete combined rail and road bridge performed surprisingly well, since in addition to being bodily uplifted some feet it was founded in estuarine deposits which evidenced liquefaction and severe slumping of embankments. The bridge was founded on vertical concrete piles. Undoubtedly, the tying together of most of the spans and piers was a vital factor in survival of the bridge and many of the piers formed "plastic" hinges at ground level (12).

Conclusion

The writer considers that seismic building design requires modification before application to river bridging, and that considerations of the relative strengths of the various components of a bridge and their connections are important and should be such as to include anticipated ground and bridge deck displacements under earthquake conditions. Further, the deck of the bridge meets ground at each end and large effects may be generated here and require rational resolution.

References

1. "P.W.D. General Instructions to Officers" Section 361 Bridges, Pg. 177.
2. "Bridge Manual" Ministry of Works 1956 Pg. 102 Clause 3.2.13.
3. N.Z.S.S. 1900 Chapter 8 - 1965 "Basic Design Loads".
4. Proceedings of the N.Z. Institution of Engineers 1945 (Vol. XXXI) "Railway Bridges of Reinforced Concrete".
5. Journal of American Concrete Institute December 1964 "Rigid Frame Railroad Bridges in Japan" by Yoshiji Matsumoto, pages 1490 and 1499.
6. Third World Conference on Earthquake Engineering, N.Z. 1965 "Some Tendencies in the Failure of Bridges and their Foundations during Earthquakes" by J. Kodera.
7. Uniform Building Code : 1964 Edition Section 2314 (k) 2. BUILDING SEPARATIONS.
8. 1969 Earthquake Symposium N.Z.I.E. paper on damage to Landing, Inangahua and Buller Bridges by J. P. Hollings.
9. "Geology and Engineering" R. F. Legget 2nd Edition Pg. 667.
10. "Standard Specifications for Highway Bridges" A.A.S.H.O. Eighth Edition 1961 page 22 clause 1.2.20 - earthquake stresses.
11. "American Civil Engineering Practice" - Abbett (1957) Vol. III page 34-30. "Earthquakes and Earthquake Resistant Design", 17 Bridges.
12. Proceedings Inst. Civil Engineers (U.K.) Volume 236 page 357.
13. "Earthquake Resistant Design for Civil Engineering Structures, Earth Structures and Foundations in Japan" compiled by the Japan Society of Civil Engineers (1960) Page 74.

14. Third World Conference on Earthquake Engineering N.Z. 1965
"General Report - Earthquake Resistant Design, Construction
and Regulations".
15. "Civil Engineering" (U.S.) August 1939 "Earthquake Studies for
Pitt River Bridge" by J. L. Savage.
16. California Department of Public Works - Bridge Across Eel River
at North Scotia Humboldt County, Bridge No. 4-15. Drawings
C-111-101 and 102.

A LETTER TO THE EDITOR,

Dunedin
5th Sept. 1968

TSUNAMI RISK

Sir, there has been much discussion as to the risk of structural damage from seismic motions in New Zealand, but I have heard little mention of tsunami risk. I have not heard of any planning to reduce this risk nor of any consideration given to the insurance risks for low-lying coastal areas.

It would be of interest to have published in your Bulletin, records of tsunami that have affected New Zealand, and I offer the following extracts.

OTAGO DAILY TIMES. 29th August 1868

"The schooner Rifleman arrived at Port Chalmers this morning, from the Chatham Islands, with a cargo of cattle and horses and a tale of great loss of property and rampaging seas. She left the Islands last Friday and has had a good return run to port.

Mr Hood, the owner of the cattle, supplies the tale - On the morning of the 15th inst. the Chathams were visited by three tidal waves, which, although not so large as those other parts have been visited by, were attended with loss of life and property.

The settlement of Tupunga, situated on the northernmost side of the island, felt the greatest force of it. The settlement was entirely destroyed; not a mark is left to tell where it stood."

MACKAY'S OTAGO AND WEST COAST GOLDFIELDS ALMANAC 1869.
AUGUST, 1868.

"On the 15th inst., a great marine disturbance occurred all along the east coast of New Zealand. At Oamaru the tide rose and fell 20 ft in a few minutes and this was repeated five times within the space of twenty minutes. At Otago Heads a similar rise and fall was observed, and inside the inner Harbour the tide rose seven knots an hour, swinging the vessels and carrying away several buoys. For a distance of over ten miles up the Taieri river, a great rise and sudden reflux of the water was also observed."

R.J. PATERSON GARDEN
M.I.C.E. F.N.Z.I.E.