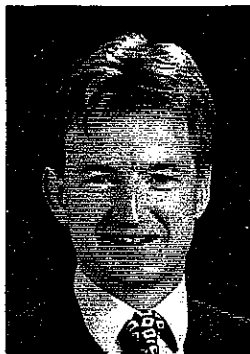


STRUCTURAL RESPONSE UNDER INTRAPLATE CONDITIONS

G.L. HUTCHINSON DPHIL MENGSC FIEAUST MICE CPENG CENG
J.L. WILSON BE MSC FIEAUST CPENG
N. LAM PHD MSC DIC BSC MIEAUST MICE MISTRUCTE CPENG CENG



Professor Hutchinson is Head of Department and Deputy Dean of Engineering at The University of Melbourne. He is President of the Australian Earthquake Engineering Society, Deputy Vice Chairman of the Victorian Division of the Institution of Engineers, Australia and Committee Member of the College of Structural Engineers of the Institution. He has written two books and over 100 papers on earthquake engineering and structural dynamics. He is also specialist consultant for earthquake engineering related projects all over the world.



John Wilson is Chairman of the Board of Engineering, Victorian Division of the Institution of Engineers, Treasurer of the Australian Earthquake Engineering Society, and Member of the Australian Standards Committee for Earthquake Loading. He was Senior Engineer with Ove Arup and Partners before becoming Senior Lecturer at The University of Melbourne in 1992. He is co-author of a book and numerous publications in many different areas of earthquake engineering and structural dynamics.



Dr Lam is a Research Fellow at The University of Melbourne. He has 14 years of structural engineering experience. He was Chartered Engineer with Scott Wilson Kirkpatrick & Partners until 1989 when he began his academic career at The University of Melbourne specialising in the field of earthquake engineering. He has produced numerous publications in many different areas of earthquake engineering.

ABSTRACT:

This paper considers each stage in the seismic evaluation procedure and highlights factors contributing to differences between intraplate and interplate structural responses as identified from recent research. Discussions cover bedrock excitations, soil amplification, inelastic structural responses, overstrength and ductility.

1. INTRODUCTION

The vulnerability of buildings and infrastructure to earthquakes is a concern in most countries, including low seismicity intraplate countries such as Australia⁽¹⁾. The seismic resistance of existing buildings can be evaluated by comparing the expected seismically induced base shear force with the ultimate capacity of the lateral load resisting system. In the absence of well established information on intraplate seismically induced loads, the earthquake loading standard for Australia⁽²⁾, (like many other earthquake loading standards around the world), are based on codes and recommendations developed in the USA, such as the Uniform Building Code⁽³⁾. In order to take into account the seismicity level of the area, design earthquake forces are adjusted using coefficients specified in local seismic hazard maps. Such seismic hazard maps have been developed from small near field or larger far field recordings and historical macroseismic data, and not from near field strong motion accelerogram recordings⁽⁴⁾.

The primary objective of intraplate earthquake engineering research is to develop means of ascertaining the seismic risks in an intraplate area. Whilst some progress has been made in understanding intraplate earthquakes in a seismological context⁽⁵⁻⁷⁾, far less is known from the engineering context concerning structural response behaviour. The lack of representative data and well documented experience has made it difficult to realistically predict the impact of future intraplate earthquakes on structures.

To study the response of structures to intraplate earthquakes, the following steps in a conventional seismic evaluation procedure must be considered. Initially, seismic hazard maps provide the acceleration coefficients to define the level of seismicity. The 'Design Response Spectrum' is then scaled according to the acceleration coefficients to predict the elastic structural response on a rock site. The effect of soil overlying bedrock is then taken into account by the 'Site Factor'. Finally, the 'Structure Response Factor' is used to predict the inelastic responses taking into account the overstrength and ductility of the structure.

The objective of the paper is to review each step in the procedure and highlight differences between intraplate and interplate conditions as identified from recent research.

2. ELASTIC RESPONSE ON ROCK

The majority of recorded intraplate earthquakes are relatively shallow and small and associated with a compressive fault mechanism^(4,8). Such earthquakes generate very high frequency, and possibly damaging, vibrations in the near field. In contrast, lower frequency damaging vibrations are typically associated with larger, and deeper, interplate earthquakes in the both near and far field⁽⁹⁾. However, both large intraplate earthquakes and shallow thrust faulting interplate earthquakes can occur although these occurrences are less common.

Further, significant variation of frequency content amongst intraplate earthquakes is common. For example, Figure 1 shows the normalised response spectra of bedrock accelerograms recorded from the magnitude 6.9 earthquake* in Nahanni, Central Canada, in 1985⁽¹⁰⁾. Although the accelerograms are recorded within 25km of each other on rock, very different response spectral shapes are found. Hence, the frequency content of intraplate ground motions can be highly variable.

* The Surface Wave Magnitude of the mainshock was 6.9. The Body Wave Magnitude of the mainshock and the aftershocks are shown in the legend of Figure 1.

3. ELASTIC SOIL AMPLIFICATION

Soil amplification is traditionally considered to be primarily dependent on the geology of the site. The UBC⁽³⁾ and AS1170.4⁽²⁾ introduces the Site Factor 'S' to take into account the effect of soil overlying bedrock on the base shear of the building. The value of S varies from 0.67 for rock to 2.0 for deep soft soil. Importantly, the peak spectral acceleration associated with the flat part of the soil spectrum is assumed to be always equal to that of the bedrock spectrum. Effectively, the spectrum "Corner Period" increases with the Site Factor.

Recent research in the United States has identified that the peak spectral acceleration in the soil spectrum can be very much higher than the corresponding bedrock spectrum⁽¹¹⁾. Further, the degree of amplification depends very much on the intensity of the ground motion. Lower intensity bedrock excitations generally result in larger amplifications. As the excitation intensity increases, amplification is gradually suppressed due to the non-linear softening behaviour of the soil.

Recent studies by the authors have further confirmed that the frequency characteristics of bedrock excitation has a very significant effect on soil amplification behaviour⁽¹²⁾. Amplification is enhanced if the soil natural frequency is close to the excitation frequency of the ground motion at bedrock level. In contrast, a deep soft soil with a long natural period will attenuate high frequency seismic waves rather than amplify them. Clearly, the response of soil to intraplate ground motions is very dependent on frequency content which is quite variable and difficult to predict.

4. INELASTIC RESPONSE OF STRUCTURES

Most structures built of ductile materials such as well detailed steel and concrete are normally designed to yield and deform significantly beyond the elastic limit when subjected to ultimate earthquake loading. It is assumed in the widely used 'Force-Based Assessment Procedure'⁽¹³⁾ that the maximum displacement of the structure is approximately equal to the corresponding elastic displacement. However, this 'Equal-Displacement' assumption is only reliable if the natural period of the structure is greater than the predominant soil natural period⁽¹⁴⁾. Much larger displacements are expected for low rise structures on rock, or for taller structures founded on soft soils⁽¹⁵⁾. Further, structures which respond in the inelastic range without a significant degradation in strength respond similarly to earthquake ground motions with similar frequent content regardless of their origins, phase-angle characteristics and durations. The excitation frequency content has been identified as the most influential factor governing the response behaviour of linearly elastic perfectly plastic structures.

The effect of regional seismicity on inelastic displacement has also been considered (publications are currently under preparation). For example, if two identical structures are each located in an intraplate and an interplate area with the same design acceleration (based on 10% exceedence in fifty years), the average ductility demand of the structure located in the intraplate area is expected to be less than that in the interplate area due to the probabilistic distribution characteristics of the earthquake intensity. Conventional seismic design procedure ignores such differences.

5. OVERSTRENGTH AND DUCTILITY

The seismic performance of a structure depends on both the system's lateral strength S_T and the allowable system ductility μ . For satisfactory performance, the ultimate displacement Δ_u should satisfy : -

$$\Delta_u \leq \mu \cdot \Delta_r \quad \text{Eq(1)}$$

where :

$$\Delta_r = \frac{S_r}{K_r} \quad \text{Eq(2)}$$

$$S_r = \Omega_{os} \cdot S_d \quad \text{Eq(3)}$$

and where Ω_{os} is the Overstrength Factor and the other variables are defined in Figure 2 .

The Overstrength Factor takes into account the increase from the design strength to the ultimate strength of a member⁽¹⁶⁾ (refer Figure 2). For a highly redundant structure where a mechanism is formed well beyond the strength associated with first yield, significant system overstrength is produced. It is considered that structures generally have system overstrength of about 2⁽¹⁷⁾. However, designers must ensure that the structure has the necessary ductility to mobilise any overstrength assumed in design. Overstrength is **not** an elastic consideration. Premature failure by shear, bond or buckling or failure at the connections must also be identified. Further, non-structural components in a structure must not be assumed to contribute to overstrength if their behaviour under earthquake is uncertain. Estimations of overstrength can be evaluated using a static push-over analysis.

The allowable system ductility depends on the kinematics of the system undergoing displacement and the strength degradation properties of individual members⁽¹⁶⁾. The kinematic effects relate the system ductility to the individual rotational ductility of a plastic hinge. Strength degradation depends on the design and detailing of individual members. The New Zealand Standard stipulates that strength degradation must not exceed 20% following four full reversed load cycles⁽¹⁷⁾. Similar criterion for intraplate conditions has not yet been established.

The quantification of overstrength and ductility of structures in intraplate areas are currently being investigated by the authors. Due to differences in the design and construction practices between interplate and intraplate countries, significant differences in overstrength and ductility are possible.

6. CONCLUSIONS

1. The frequency content of intraplate earthquake excitations are highly variable.
2. Intraplate soil amplification is also highly variable as it depends not only on the soil properties of the site but also on the intensity and frequency characteristics of the bedrock excitations.
3. The inelastic displacement of a structure may significantly exceed the equivalent elastic displacement depending on the natural period of the structure in relation to the soil natural period.
4. The probabilistic distribution of intraplate earthquake intensity contributes to some reduction in the ductility demand.
5. The seismic performance of a structure depends on the overstrength and ductility which in turn depends on the structure's design and detailing at both system and member level. Thus,

overstrength and ductility factors associated with intraplate regions could be different from interplate regions.

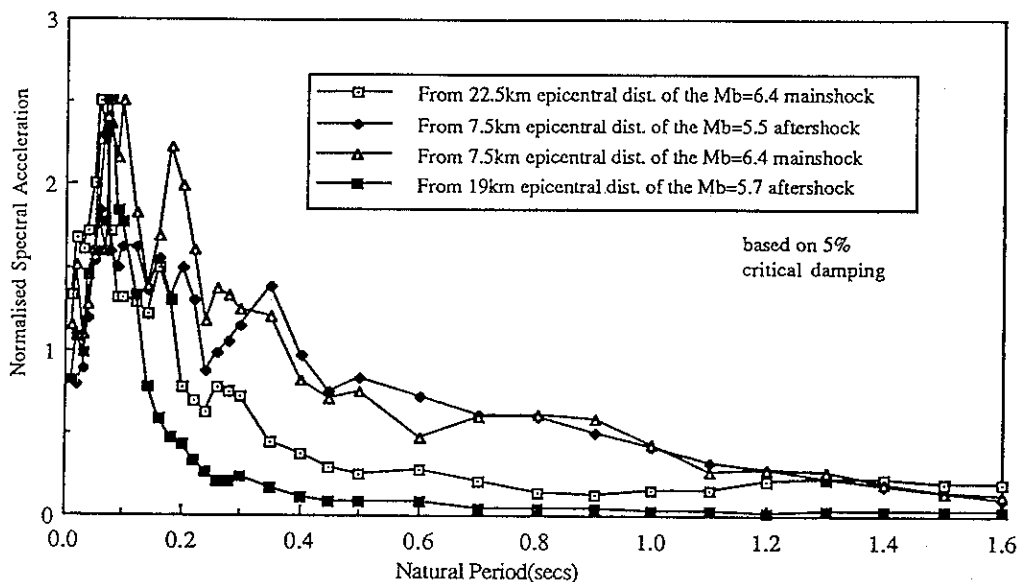


Figure 1 - Normalised Response Spectra of Accelerograms Recorded at Nahanni, Central Canada, in December, 1985.

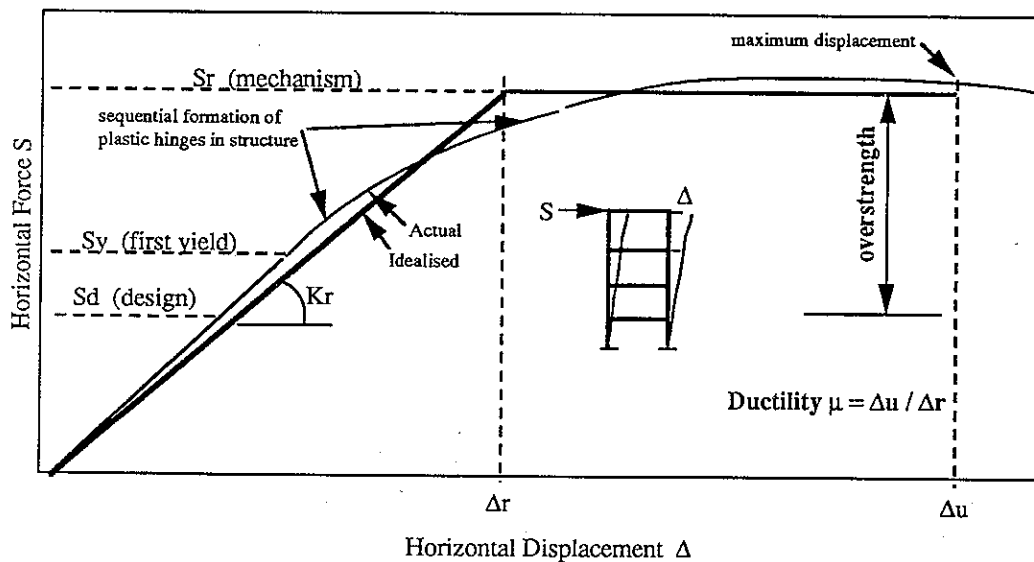


Figure 2 - System Overstrength and Ductility

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