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論文題目	A Study on Seismic Design for Infrastructures in a Low Seismicity Region （地震活動度の低い地域における土木構造物の耐震設計法に関する研究）		

（論文内容の要旨）

Countries such as Malaysia, although situated on the stable seismicity zone of the Sunda plate, has been reported to record small to medium size locally generated ground motions, and has been affected by distant earthquakes from the active seismic sources of Indonesia and the Philippines. Seismic risk is perceived as considerable when there is a lack of seismic resistance in bridge structures. Such situation is common in low seismicity countries because the design of bridges in these countries continues to follow the traditional method of accounting for vertical loads and a small percentage of horizontal loads, such as that calculated to resist wind loading. Therefore, exposure of these bridge structures to seismic loads may be devastating. In line with human security engineering, there is enough warrant to begin seismic resistant design of bridges, as well as to investigate the vulnerability of existing bridges to seismic forces in countries belonging to the low seismicity region.

In view of the above scenario, the main objective of this research is to clarify an advanced concept of seismic design for bridges in a low seismicity region such as in Malaysia. The ultimate aim of this research is to derive an acceptable seismic design coefficient and allowable ultimate displacement to incorporate in the current bridge design code as a measure to secure the public safety against the potential destruction brought about by an earthquake motion. This thesis consists of 8 chapters, as follows.

Chapter 1 is the introduction of the thesis. The problems to perform seismic design of infrastructure are summarized and the objectives of the research are clearified.

Chapter 2 provides a brief review of the seismic hazard and seismicity conditions in Malaysia to understand the seismicity of Malaysia, as well as to justify the need for evaluation of a seismic design motion for the country. A larger remaining portion of this chapter is attributed to giving an overview of the performance-based design, displacement-based design, and nonlinear static pushover analysis employed in the course of evaluating a seismic design motion for Malaysia. A brief mention of the OpenSees software is made in this chapter to highlight the features, and advantages of using an open source software framework in the analysis of a bridge.

Chapter 3 is dedicated to investigating the characteristics of distant ground motions in Peninsular Malaysia, which originated from the active tectonic plate of Sumatra. The methodology employed is by comparing recorded peak ground acceleration (PGA) and peak ground velocity (PGV) values of ground motions recorded by the Malaysian network of seismic stations with those estimated using established attenuation. Results of analysis show that attenuation characteristics of ground motions for Peninsular Malaysia can be appropriately represented by attenuation models established for stable tectonic region. In conclusion, the Dahle et al. (1990) model best represents the attenuation characteristics of ground motion in terms of PGA, while the Atkinson and Boore (1995) model may appropriately estimate ground motion in terms of PGV for far earthquakes. In addition, this chapter also discusses about estimating the maximum magnitude earthquakes, which are expected to occur within inland Malaysia. In reference to the available historical earthquake data, it is proposed that the maximum magnitude earthquake for Peninsular Malaysia is 6.5. Based on this magnitude, the PGV and peak ground displacement (PGD) are estimated. Therefore, it is proposed that the seismic performance evaluation of the bridge, in chapter 4 of the thesis, should employ large acceleration ground motion, such as that recorded by the 1995 Kobe earthquake.

Chapter 4 introduces the procedure for conducting seismic performance evaluation and presents how the existing brige is modeled for the performance evaluation. “Samudera Bridge”, which exists in Malaysia, is selected for the analysis. A multiple-degree-of-freedom (MDOF), three-dimensional model was developed in OpenSees and used in the later analyses.

Chapter 5 shows the result of non-linear static push-over analysis to estimate deformation capacity using the numerical model developed in the previous chapter.　The results gathered from the pushover analysis indicate an important deduction on the displacement capacity of pier sections with unequal dimensions. For this bridge structure, the pushover curve has illustrated that in the longitudinal direction, although the pier section is thin and the seismic coefficient is small, it possesses a large displacement capacity.　In the transverse direction, although the pier section is thicker, and the seismic coefficient is larger, the displacement capacity in that direction is lower.

Chapter 6 was subjected to seismic simulation under the excitation of three input ground motions, namely the 1995 Kobe, 1940 El Centro and 2005 Sumatera earthquakes.　Observation of the damage during dynamic analysis, for instance under the Kobe excitation, indicates that the piers in the transverse direction suffer severe damages even though they have high seismic coefficients. In contrast, piers having lower seismic coefficients survived the excitation, although they have lower seismic coefficients.　Thus, it can be deduced that seismic coefficient is not an important factor to survive a large excitation.　Rather displacement capacity plays an important role in ensuring survival during a large ground motion.

Chapter 7 explores the impact of introducing seismic resistant design on the cost of bridge constructions.　The methodology used involves examining the level of ductility in the pier section by employing the nonlinear pushover analysis.　Results of comparison of seismic performance in the transverse direction and construction costs between the original section, which is used in the previous chapteres, and the modified (downsized) section, which is designed by "flexible design concept", show that the modified section has more seismic performance and be less expensive.　This chapter also discusses the impotance of fail-safe mechanisms.　It is concluded that a part of reduced cost in the flexible design should be used to install fail-safe mechanisms for seismic risk mitigation.

Chapter 8 is the conclusion. The knowledge obtained in the research is summarized.

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（論文審査の結果の要旨）

日本やアメリカ西海岸地域のように地震活動度が高いところでは，マグニチュード７程度以上の地震が頻繁に起こるため，これらの地震による地震動を予測し，これに耐えうる耐力を与えるような耐震設計が実行されている．一方，マレーシアのような地震活動度の低い地域においては，どの程度の地震動の大きさに対してどのような耐震設計を行えば良いのかについては，十分な検討がされていない．本研究では，このような地域における耐震設計のコンセプトについて研究した成果についてまとめたものであり，得られた主な成果は次のとおりである．

１．地震動記録が非常に少ない地域で用いることのできる距離減衰式の選定方法を提案している．これにより遠方の地震活動域で発生する大規模地震に対する設計地震動を評価することが可能となる．さらに，地震活動が活発でない場所でどのような地震を想定すべきかについての議論を展開し，設計地震動として考慮すべき具体的な数値を導いている．これらの検討によって，地震活動度の低い地域における土木構造物の設計地震動を評価する方法を提示した．

２．マレーシアに実在する２７基のＲＣ単柱橋脚からなる２８スパンの道路高架橋に対して，ファイバー要素による非線形モデルを構築し，３次元非線形解析を実施して，その耐震性能を調べた．その結果，橋軸直角方向は耐力が大きいが変形性能が小さく，橋軸方向は耐力は小さいものの変形性能が大きいため，神戸海洋気象台記録を入力した動的非線形応答解析では，橋軸直角方向には倒壊状態となるが，橋軸方向は終局変位を超えず倒壊を免れることがわかった．これらの検討によって，地震活動度が低い地域では耐力を大きくするよりも，変形性能を重視した耐震設計が合理的であることを示した．

３．マレーシアのような地震活動度の低い地域にある開発途上国では，耐震性能を向上させるために多くのコストを費やすことが難しい．そこで実在する橋脚と，柔構造化するためにその断面を小さくした橋脚で，耐震性能とコストの関係を検討した結果，断面を小さくすることでコストを下げても変形性能が向上するために十分な耐震性能が確保できることを確認した．また，もし設計地震動を超えた場合でも破滅的な破壊に至らないようにするためのフェイル・セーフ機構を導入することの重要性についての議論を展開し，柔構造設計を導入する場合には，剛構造に比べて安くなったコストの一部をフェイル・セーフ機構のために使うことを提案している．

以上のように，本論文は，地震活動度の低い地域における土木構造物の耐震設計法について包括的かつ多面的に検討した結果をまとめたもので，学術上，実際上寄与するところが少なくない．よって，本論文は博士（工学）の学位論文として価値あるものと認める．また，平成 24 年 1 月 25 日，論文内容とそれに関連した事項について試問を行って,申請者が博士後期課程学位取得基準を満たしていることを確認し,合格と認めた．