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論文題目	Integrated Earthquake Risk Evaluation for Mega-Thrust Earthquakes （統合化された海溝型巨大地震リスク評価に関する研究）		

（論文内容の要旨）

This study aims to propose an integrated risk evaluation system for mega-thrust earthquakes based on information of past earthquakes, damage surveys, geophysical surveys, and observed data, considering the urgent needs toward more quantitative risk evaluation for future mega-thrust earthquakes. The potentials of the proposed techniques for evaluating the site and source characteristics, building damage, and human loss by tsunamis are examined, all of which are indispensable and tightly connected to each other for evaluating the clear and present risk of mega-thrust earthquakes. This thesis consists of 10 chapters. It is intended to update and integrate techniques in evaluating the potential risk of mega-thrust earthquakes. The content can be summarized as follows:

In Chapter 1, the background and purpose of this study are introduced. It is noted that all disasters are complex and predicting disasters can only be accomplished through the integrated use of technologies that cross many different disciplines inevitably. The current progress of each evaluation method is reviewed and challenges associated with earthquake risk assessment is described and the possible solutions are discussed.

In Chapter 2, a simple method is proposed to deduce the horizontal site amplification factor in the S-wave portion directly from the earthquake horizontal-to-vertical spectral ratios of observed earthquake ground motions. This method utilizes the vertical site amplification factor multiplied by the vertical-to-horizontal ratio at bedrock to determine the empirical vertical amplification correction function. The method is capable of evaluating site effects of S-waves based on observed values in a wide frequency range from 0.12 to 15 Hz. It should be noted that the proposed method can obtain the horizontal S-wave amplification factor from the seismological bedrock, rather than the engineering bedrock, to the ground surface.

In Chapter 3, the method of the earthquake-to-microtremor ratio of horizontal-to-vertical spectral ratios (EMR) is applied to a basin in a region tectonically different from Japan. The EMR specific to the target site, the Grenoble Basin, is assumed to follow the general function shape as the EMR for Japanese basins, which is the power of α of EMR. The optimal α is found to be 0.28 for the Grenoble Basin case. As the first attempt toward the final goal to delineate the whole basin structure in a tectonically different environment from Japan, an overall picture of the Grenoble Basin from observed microtremors by using a new scheme proposed here were successfully obtained.

In Chapter 4, an empirical method to correct the one-dimensional (1D) theoretical site amplification factor is proposed to evaluate an equivalent 1D S-wave site amplification factor at an arbitrary point. The original site amplification factors were calculated from the unified velocity model of the National Research Institute for Earth Science and Disaster Resilience for the Kanto and Tokai regions. Validation examples showed that the proposed method can effectively predict better site amplifications than the direct substitute of 1D theoretical amplification factors at a site without observed data.

京都大学	博士（　工　学)	氏名	伊　藤　恵　理

In Chapter 5, the source process of past mega-thrust earthquakes and ground motions that were not recorded in the past is clarified by adapting the simulated strong motion waveforms to the results of the damage survey. As the overall characteristics of the calculated synthetics, it was found that the current implementation of the complex source model used as a broad-band kinematic source representation and the empirically-determined statistical Green function used as an elemental source of strong motions, can be a viable combination for realistic broad-band strong motion simulations without any hybrid scheme.

In Chapter 6, analyses are conducted to elucidate the heterogeneous source rupture propagation process of the 1944 Tonankai earthquake. The results show that to explain the building damage ratio over 40%, it is necessary to consider a source rupture process that causes stronger forward rupture directivity effect in the Enshu region. The proposed building damage evaluation model and the distribution of the observed damage ratio provide a prospect to clarify the detailed source rupture process of the 1944 Tonankai earthquake.

In Chapter 7, a set of tsunami evacuation simulations focusing on urbanized areas are conducted by considering building damage ratios from the building damage simulation model, and evaluate the human loss considering the effects of collapsed buildings during the tsunami evaluation in the target area. Even in districts with higher awareness about tsunami disaster and well-prepared evacuation planning, it was found that there are unresolved issues. This study quantified the risk of collapsed buildings in the evacuation process through the use of a building collapse ratio simulation. This will be a significant contribution to future studies and disaster reduction planning.

In Chapter 8, tsunami evacuation simulations for a village with stiff soil layers are performed considering the building damage ratios obtained by the building damage prediction models specific to the area and the best strategy of the evacuation plan in the target area was explored. The tsunami evacuation simulations showed that 95% of residents can complete evacuation within 20 minutes after the earthquake, and hence starting evacuation in five minutes after the earthquake has a high probability of mitigating danger of being caught in a tsunami. The reason that the number of successful evacuees was larger when the evacuation start time of residents in collapsed buildings was delayed, is because the shift in evacuation start time reduces congestion in very narrow roads and near road blockades.

In Chapter 9, tsunami evacuation simulations are conducted to extract the difficult-to-evacuate area (DEA) for an area where there is insufficient awareness on evacuation among residents and administrative agencies are on the way of making evacuation plans. Reflecting the results of thorough analysis, the central district in the target area was found to be the DEA. A countermeasure to additionally designate an office building as an evacuation facility in the area was proposed, which made casualties of the DEA decrease from 12% to 2% of the total population of the area.

In Chapter 10, the conclusions and remarks from each chapter of this thesis are summarized.

（続紙 ２ ）

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（論文審査の結果の要旨）

本論文は、過去の地震の際に被害を受けた地域での定量的被害シミュレーションを行うことで被害要因を分析し、将来発生が予想される地震によって引き起こされる人的被害の適切な予測につなげることを目的としている。これは、平成 23 年（2011 年）東北地方太平洋沖地震による被害に関する既往研究の分析から、巨大海溝型地震の定量的なリスク評価のためには、建物被害に影響する地震動特性（震源・伝播経路・サイト特性）、人的被害に影響する建物被害、および人的被害の予測等に関する既存の各評価手法を拡張し統合することが重要であるという考えに基づいている。本論文は、この目的を達成するために、地震時の人的被害予測に向けた各評価手法の提案とそれらの統合化に取り組んだものであり、得られた主な成果は以下に示すとおりである。

１．経験的サイト特性評価法として、地震動の上下動の増幅特性を考慮するための補正関数により、水平上下スペクトル比からＳ波部分の水平動サイト増幅率を推算する方法を提案し、その有効性を検証した。また、地震記録が少ない場合に、その地域に固有の地震動・微動の水平上下スペクトル比を用いて地下構造を逆算する方法を提案し、その妥当性を示した。さらに、サイト増幅特性の理論解と経験値の差異を補正する係数を新たに提案し、その補正係数が有効であることを示した。

２．統計的グリーン関数法と不均質震源モデルを用いた強震動予測手法を提案し、1944 年東南海地震を対象にして、設定する破壊開始点、強震動生成域位置、応力降下量が異なる震源モデルとサイト増幅特性の補正係数を用いて強震動波形を計算した。これらを戦前の建物の被害評価モデルに入力して当時の建物倒壊率を算出し、観測倒壊率と比較することで、最も観測事実を説明できる短周期域の震源像を明らかにした。

３．エージェント・ベースの津波避難シミュレーションを用いた人的被害評価手法の拡張を行い、巨大海溝型地震の震源域近傍に位置する中規模市街地と小漁村を対象として、建物倒壊を考慮した津波避難シミュレーションを行うことで対策立案に資する知見を提示した。また、現実的な津波避難シミュレーションを用いて避難未完了者分布の目視分析と避難未完了者に関する指標に基づいて総合的・効率的に避難困難地域を抽出する方法を提案し、その有効性を明らかにした。

以上を要するに、本論文は巨大海溝型地震による被害予測のための統合化された評価手法の確立に資する各評価手法の新たな拡張方法を提案し、より高精度な地震リスク評価の可能性を提示したもので、巨大海溝型地震による地震リスク評価について学術上、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、令和３年２月１５日、論文内容とそれに関連した事項について試問を行った結果、合格と認めた。