Study on Ground and Structural Vibration Reduction using Periodic Wave Barriers(周期的波動遮断体を用いた地盤と構造物の振動低減に関する研究)

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論文内容要旨

Chapter 1: Introduction

Seismic waves, machine foundation, traffic or blasting generate waves that can adversely affect nearby structure and operation of sensitive equipments. Various countermeasures have been advised to reduce the ground-transmitted vibration, conventionally the installation of trench, base isolation or active mass driver. In any vibration reduction problem, one needs to clarify the desired frequency to be cut. This can be done by identification of the source, propagating path or the structural vibration characterization. To clarify the structure vibration characteristics, calculation method based on the structure physical member can be done, but more reliable values can be obtained by vibration test. Using such test, natural frequency and damping of the system can be obtained. Several methods have been applied for structure vibration test such force vibration using exciter, microtremor and earthquake observation data. The use of wide frequency range exciter, that can reproduce the same load, looks important for this purpose. It will be shown that the Land Air Gun Impactor, which is commonly used in geological reflection survey, can be applied for generating the dynamic load. The wide frequency range and reproducibility of generated wave make it a right tool for vibration test. The problem of screening of the incident wave by deep trenches, canyons or rock zone was observed in the past by the seismologists and earthquake engineers. These natural phenomena lead to the use of wave barrier (open or in-fill) to control the propagating waves due to the vibration or seismic incident wave. In the recent years, extensive numerical researches have been done to study the effect of single wave barrier on the reduction problem. In all this studies, no attention was given to the possibility of screening of the waves by periodic wave barriers. A periodic system, which consists of number of identical element joint together in an identical manner, is well known for its filtering effect. The filter action in a periodic system is caused by the destructive interference between the incident waves and their reflected components. The propagation cannot be done in certain frequency ranges known as attenuation zone or stop band. Using the vibration characteristics information obtained form vibration test, a periodic system can be designed to cut the unwanted waves in the attenuation zone of its periodic element.

The aim of this study is to present a new method for structural vibration test using land air gun impactor and to introduce a passive device to isolate the unwanted waves transmitted in the ground and controls the structural vibration.

Chapter 2: Application of Impulsive Load on Structural Vibration Characterization using Land Air Gun Impactor

The purpose of this chapter is to introduce a new device to investigate the vibration characteristics of the actual building. Different ways exist to get a dynamic load, namely seismic waves, microtremor and vibrator. The dynamic behavior of the structures needs to be considered when special loads, like earthquakes or collisions or explosions, may be expected on a structure. Through measurements, we can access to the vibration characterization of the structure or whether the structure is damaged and harmed. In this study a Land Air Gun Impactor machine, which is commonly used in geological reflection survey, is used to generate the dynamic load. The nine-story steel-reinforced concrete (SRC) building of the department of Architecture and Building Science of Tohoku University at Aobayama campus is selected to confirm the new device. The results of the previous test and vibration test done after the completion are used to show the applicability of this device. By using this machine, the structure vibration characteristics can be obtained and based on the results, a suitable countermeasure to reduce the unwanted frequency can be decided, which will discuss in the next chapters. The building is extensively instrumented for the test in order to clarify the possible motions. The scope of this study is limited to the significant findings in data analysis. A brief discussion is also done for historical changes of the fundamental frequency of the building.

Chapter 3: Parametric Study of One-Dimensional Periodic Wave Barriers

Many types of structures are built up of an assembly of nominally identical or repeated elements, couple together in an identical manner to form the whole structure. A structure of this type forms a periodic structure. Wave motion and propagating wave in such a system is possible only in certain frequencies band, known as propagation zones and the frequencies which the waves can not propagate are known as attenuation zones. In this chapter, first the theory of the propagating wave in such a system is discussed. Then a one-dimensional periodic wave barrier is parametrically investigated. The effects of barrier's width, spacing, contrast and numbering are discussed. From 1-dimensional model, it is shown that low velocity barrier is effective in lower frequency range, while a high velocity one can be used to reduce the higher frequency range. Although a single barrier can reduce the ground-transmitted wave's amplitude, but the use of periodic wave barriers can be more effective in the attenuation zone of the periodic system. The screening effect can increase by increasing the number of barriers. By changing the barrier's material property, width or spacing one can define the desired frequency range to be reduced in ground response.

Chapter 4: Ground Transmitted Wave Reduction using Periodic Wave Barriers

The ground transmitting wave's reduction by means of periodic wave barriers is investigated for vertical and horizontal barrier in a simple 2-D model. Plane surface wave (Rayleigh) and vertical point load are applied for vertical periodic barrier and vertically propagated shear body wave for the horizontal barrier. It is shown that the periodic wave barriers can be a proper device to control the ground-transmitting wave. This passive device can

reduce the wave's amplitude in the attenuation zone of the periodic element. It is also shown that in lower frequencies, a deeper wave barrier is more effective than a shallower one. For layered half-space model, although reduction occurs in attenuation zone of the periodic element but amplification around airy-phase of surface wave is observed, which is due to constructive interference of surface wave and diffracted waves. Reduction of 50-90% is observed in the screening area. For the vertical point load, however the screening occurs, but due to circular nature of the wave, some amplified regions appear. This may be due to the multi-diffracted wave and the critical angle problem in the layer half-space. The horizontal barrier can also be used to reduce the incident body wave. This periodic barrier can reduce wave's amplitude in a wide frequency range.

Chapter 5: Structural Response Reduction using Periodic Wave Barriers

The structural response reduction using periodic wave barriers is analytically investigated due to ground-transmitted waves, such as traffic-induced wave. The structure model has been made based on the actual building investigated in chapter 2. Using the frame elements, the reduced model has been made considering only the horizontal motion in NS direction (transversal). The frequency dependent soil springs, horizontal and rocking, are calculated and added to the model. The driving forces are calculated for line source away from the structure. The response of the structure is compared for the cases with and without the periodic barriers. It is shown that the periodic wave barriers can reduce the structural response in the range of attenuation zone of the periodic system. An amplitude reduction of 70% is obtained in the investigated model.

Chapter 6: Concluding Remarks

The idea of the filtering effect of a periodic system, which can filter the waves in the attenuation zone of the periodic element, is used in this study. Although a single infill trench can reduce the amplitude of the ground-transmitted waves, it is shown that the periodic wave barriers can be used as a passive isolation to reduce the ground-transmitted waves in the attenuation zone of the periodic system. In any vibration reduction problem, one needs to clarify the desire frequency to be cut, that can be done by the identification of the source, propagating path or structural vibration characterization. A new device is introduced for structural vibration. The Land Air Gun Impactor, which is commonly used in geological reflection survey, is used for this purpose.

論文審査結果の要旨

地震動、機械振動、交通振動、あるいは爆風などの動的外乱に対する周辺の構造物や高感度の設備機器の振動低減問題は構造工学や地震工学における重要な課題の一つである。本論文では、周期的波動遮断体により特定振動数域における地盤や構造物の応答低減を行う方法を提案するとともに、構造物―地盤系の高振動数域に及ぶ振動特性を把握するために、インパクターを用いた振動試験法を検討したもので、全編6章よりなる。

第1章は序論である。

第2章では構造物―地盤系の振動特性を把握するための試験法として、地盤調査法の一つである反射法探査に用いるインパクターを加振源とする方法を提案している。実際の建物として東北大学工学研究科の人間環境系研究棟（鉄骨鉄筋コンクリート造9階建て）を対象として、その近傍地盤においてランドエアガン型のインパクターを用いた加振試験を行うことにより得られる衝撃応答関数的な応答波形を分析することで実存構造物―地盤系の高振動数に及ぶ振動特性を同定している。

第3章では周期的波動遮断体を対象とした1次元波動伝播問題に関する基本的な検討を行っている。すなわち、周期的波動遮断体への入射波に対し、遮断体と地盤の波動インピーダンス、配置間隔、および遮断体の数により遮断振動数域と透過振動数域を区分する遮断振動数や遮断効果がどう変化するかをパラメータ・スタディにより理論的に検討している。この理論的検討に基づき、遮断体の物性を変化させることにより遮断振動数を望ましい振動数に調整し、振動低減を行うことが可能であることを示した。

第4章では周期的波動遮断体を地盤に設置した場合を対象に2次元波動伝播問題としての解析的検討を行っている。受動的振動低減装置として周期的波動遮断体を2層地盤に水平方向や上下方向に配置した場合に、平面波入射や上下方向の点加振力に対する地盤やその上に設置される構造物の応答がどの程度低減するかを解析的に検討している。この検討により、地盤や構造物の応答が周期的波動遮断体により形成される遮断振動数域において低減することを解析的に示した。

第5章では第2章で示した実存構造物―地盤系を対象に、通行車両により発生する振動を低減するための方法として周期的波動遮断体を用いた場合の検討を行っている。建物の振動解析モデル化は梁・柱・壁をモデル化したフレームモデルから出発し、リダクションにより各階に水平方向の自由度を持つモデルを作成し、これに基礎のスウェイ変形とロッキング変形を考慮した解析モデルを作成している。通行車両を対象とした振動源により発生する波動が地盤を介して構造物に入射する場合の応答低減効果を検討している。

第6章は結論である。

以上、要するに本論文は、周期的波動遮断体の遮断特性に着目し、これを受動的制振装置として用いることにより地震動や交通振動に対する地盤と構造物の応答低減を行う方法を提案したものである。振動低減を効率的に行うのに必要となる構造物―地盤系の振動特性を把握するための試験法としてインパクターの利用を合わせて提案するなど有用な知見を提供したもので、構造工学、及び地震工学における構造物―地盤系の振動低減に関する研究分野の発展に寄与するところが少なくない。

よって、本論文は博士（工学）の学位論文として合格と認める。