DEVELOPMENT OF A SITE-SPECIFIC, SPECTRUM COMPATIBLE DESIGN ACCELEROMETER USING STRONG MOTION RECORDS

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ABSTRACT

Earthquake wave amplification at a particular site, due to local soil conditions, causes severe damage to infrastructures, including both ground structures and buildings. In conventional design practices wherein a generalized design response spectrum is used, it is difficult to capture effectively the frequency characteristics of the local site condition and the characteristics of past earthquakes at that particular location.

The objective of this research is to create a design input accelerogram at a particular site using an earthquake strong motion database. The Tokyo Metro Co., Ltd. had placed a series of strong motion accelerographs, across various locations in Tokyo, at different depths, creating an earthquake strong motion database spanning around 40 years. The local site conditions of the location are also available through boring reports. For the current study, digital seismic data collected since 1999 for Tokyo Metro stations Hiroo, Shinkiba and Toyocho are used.

The frequency characteristics of the recorded data are analyzed, and the general patterns in the bed-rock to surface transfer amplification function are discussed. The response spectrum of each

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strong motion data is normalized with $\sqrt{PGA \times PGD}$. The average normalized response spectrum is compared with the frequency characteristics of the recording station.

To compute the earthquake wave amplification at the recording site, methods based on the 1-D wave propagation theory, using equivalent linear models, namely SHAKE and DYNEQ are used. The validation of these methods is performed with the recorded data. The design earthquake input at engineering bed-rock level, used in conventional design practices in Japan, are convoluted through the soil layers to obtain the amplified earthquake wave at the surface. Two levels of earthquake viz. the high return period L1 earthquake and low return period L2 earthquake are considered. From the normalized spectrum and the convoluted earthquake wave, the design spectrum is obtained. A spectrum compatible design earthquake wave is generated using the Ohsakis’s method. Through de-convolution the design earthquake at the engineering bed rock level is obtained.

The developed design accelerograms consider the wave amplification due to local site conditions as well as the frequency characteristics of the past recorded data. The advantage of the proposed method lies in simplicity, through the usage of methods which are widely used in field of earthquake engineering.
Template for Paper submission to the Eleventh U.S. National Conference on Earthquake Engineering

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ABSTRACT

This paper discusses the development of a method to generate a spectrum consistent earthquake design input motion using a database of strong ground motions, recorded by sensors buried at different depths at various locations in Tokyo since 40 years by Tokyo Metro Co., Ltd. Using the average response normalized data and the design response spectrum at engineering bedrock, a site-specific design response spectrum is obtained. The Ohsaki’s method is used to generate a spectrum consistent acceleration time history. The local site conditions of the location are also considered, using conventional seismic ground response analysis tools like EERA and DYNEQ. Through the combination of the methods above, a design accelerogram is developed, which considers the wave amplification due to local site conditions as well as the frequency characteristics of the past recorded data.

Introduction

Japan is considered to be an earthquake-prone country and potential for large earthquakes is significant here. In the presence of a gap in massive earthquakes in Tokyo makes a threat to the built environment on and below the ground here. Prior knowledge of the site-specific earthquake forces acting on structure could be an invaluable resource to prepare for impending catastrophes. Structures need to be designed for a higher level of earthquake input, which has a higher return period. This can be achieved from the history of ground motions records from the past earthquakes and local soil conditions.

The Tokyo Metro Co., Ltd.[1] has placed a series of strong motion accelerographs, across various locations in Tokyo, at different depths, creating an earthquake strong motion database spanning around 40 years. The data which mainly consists of raw acceleration time histories are zero corrected and filtered. Further, they are analysed through the Response Spectrum Analysis and Fourier analyses. To incorporate all the data, normalisations schemes have been considered to obtain a single response spectrum by preserving the site condition in the response spectrum [2], [3].

In this study, the data recorded since 1999 at Tokyo Metro station: Shinkiba is used and the soil data is obtained from the borehole reports. The shear wave velocity is calculated using the N-value from SPT test through the empirical relationship given by the Japanese Highway Bridge

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Design Code as mentioned in [4]. In conventional practice, to predict the amplification of ground motion at a particular site, the site is assumed to be stratified into horizontally layered soil deposits, and the amplification is created through a 1D shear wave propagation through these layers. Though the behaviour of soil is highly non-linear, equivalent linear models are used to simplify the modelling. To consider the local wave amplification of the earthquake, two simulation tools have been used, viz. EERA [5] and DYNEQ [6]. To consider the design earthquake accelerograms (L1 and L2) at the bedrock, the design standards specified by RTRI is used in this study [7].

**Methodology**

![Figure 1. Overall methodology of the current methodology](image)

The overall flow of the work is as shown in Figure 1. Two design earthquakes in Japan is considered, L1 and L2, the medium earthquake with low return period and a massive earthquake with high return period respectively. These design accelerograms are taken at the engineering bedrock, which is further transferred to the ground by using equivalent non-linear ground response analysis EERA and DYNEQ. Both the techniques efficiently considers the local site conditions effectively. Response spectrums of observed ground accelerograms from the large database are generated. Further, it is normalised by using [3] and averaged into one response spectrum. This is revoked with the peak ground parameters from the previously transferred design accelerograms at the surface. This gives two accelerograms for L1 and L2 earthquakes, which are transferred to accelerograms by using Ohsaki technique at the surface. The general flow of Ohsaki method is shown in Figure 2. This accelerogram is deconvoluted to the bedrock by using non-linear ground analysis to obtain design bedrock accelerogram.

**Results**

Firstly, a normalised response spectrum is obtained for the surface is as shown in Figure 3 using
the normalisation proposed in [3]. Then the PGA, PGV and PGD values are obtained from the ground response analysis of L1 and L2 earthquakes. The obtained values are used in the normalized spectrum to obtain the design accelerogram at the surface of the ground as shown in Figure 4.

Step 1: Assume envelope function and random phase difference distribution

Step 2: Generate ground motion from Target RS spectrum (Inverse Fourier Transform)

Step 3: Compare Response Spectrum and re-iterate till convergence

Discussions

To be able to consider the local site conditions bedrock accelerograms have been convoluted from bedrock to ground by using equivalent ground simulations tools EERA and DYNEQ. In case of large earthquakes, there was an overestimation of stress and effective strain at high frequency, make it difficult to model the wave propagation of large earthquake wave through a
soil medium using EERA. However, both the techniques efficiently considered the local site conditions effectively, but when the ground acceleration of the earthquake is large, better correlation with recorded data was observed with DYNEQ. Although useful in engineering applications, the results of seismic response tools like EERA and DYNEQ are highly dependent on the analysis parameters and soil properties. The nonlinear material behaviour varies on other factors like effective stress, groundwater elevation, the age of soil deposit etc. As, the analysis results are highly dependent on the material non-linearity, especially in the case of large input earthquake motion, hence better models are required.

The normalisation of response spectrum seems reasonable, but it is valid with limited evidence from the literature. Also, currently as only two (PGA, PGD) of the various available parameters are used for normalisation [3], further study is required to ascertain a better normalisation method.

Conclusions

A method is proposed to use past recorded strong motion data at a particular site, to generate a design ground motion for that particular site. The advantages of using equivalent linear earthquake response analysis, to predict the ground wave propagation was observed. In addition to the design earthquake ground motion, the big data of accelerograms has many useful applications as it can be used in the area of disaster response and recovery. By having real-time data recording, during the onset of an earthquake, a quick analysis of the data can be done and compared with the database of past motion, for quick assessment of damage. This helps in decision making, and efficient usage of resources post-disaster.

Acknowledgement

The authors gratefully acknowledge Tokyo Metro Co., Ltd. for the funding and resources (recorded ground motions and borehole data) to carry out this research. The authors also thank Mr. Katagiri T (Technical Director, IIS, University of Tokyo) and Mr. Sato S (Tokyo Metro Co., Ltd.) for their technical advice.

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