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Effects of Resonance between Spatial Structures and Ceiling Systems on the Seismic Response

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Abstract

Spatial structures such as a gymnasium and an exhibition hall often use the ceiling because of sound effects. On the other hand, the ceiling members fell down on a large scale. This is the reason why it is needed to investigate effects of resonance between spatial structures and ceiling systems on the seismic response. This study gives structural engineers a lesson to design the earthquake-proof design of the ceiling system. In particular, the specification of the connection detail is important for the vibration.

Keywords: large span structures, arch rigid frame, ceiling system, earthquake response, resonance, seismic design coefficient, , earthquake design, time history response analysis.

1. Introduction

Large span structures sometimes set up ceiling systems for insulation to reduce heating bills and soundproofing to use as an auditorium. Although the earthquake-proof design for the non-structural member on the ceiling system is necessary to prevent the fall due to the vibration, the design is not carried out as well as the other non-structural member.

It is known by reports on the past earthquake disaster that ceiling boards of spatial structures fall down due to the roof response. In particular, the ceiling board is absolutely dangerous to life in the building.

The purpose of this study is to investigate he dynamic behavior of spatial structures subjected to earthquake motion. And also the calculation method is shown to predict the natural period of the ceiling.

Resonance curves are presented using the dynamic interaction between spatial structures and ceiling members. The collapse mechanism is significant to carry out the earthquake-proof design. The seismic design load including the resonance amplitude is presented to verify the safety comparing between the stress and the strength of the ceiling.

2. Response of ceilings based on the vibration characteristics of spatial structures

The basic thinking behind setting up input ground motion for seismic design and analyses are described in this section. There are two basic focal points:

(1) Designing is to basically a two-phase design procedure, Level 1 (moderate earthquake motion) and Level 2(severe earthquake motion), with seismic design carried out for these earthquake inputs.

(2) The input ground motion for design is to be defined for the basement layer, with the Vs, shear wave velocity, being about 400m/s or more.

2.1. Seismic design coefficient of ceilings

The ceiling response (E) is shown in Fig.1 is induced by the floor response (D) due to ground motion (B) with amplification characteristics of the surface layer (the layer B) in relation to predominant periods of the layer. The input ground motion (C) for the design is to be defined for the engineering bedrock (the layer A), with the shear wave velocity being about 400m/s or more.

The inertia force F_H must be set up considering the most important factors as follows:

$$F_H = K_H W \tag{1}$$

$$K_H = Z\beta_H k_H K_0 \tag{2}$$

Where K_H=the seismic design coefficient, W=the weight of the ceiling, Z=the seismic hazard zoning coefficient, k_H=the seismic design coefficient determined by the roof amplification ratio, β_H=the seismic design coefficient determined by ceiling amplification ratio, and K_0=the standard seismic design coefficient.

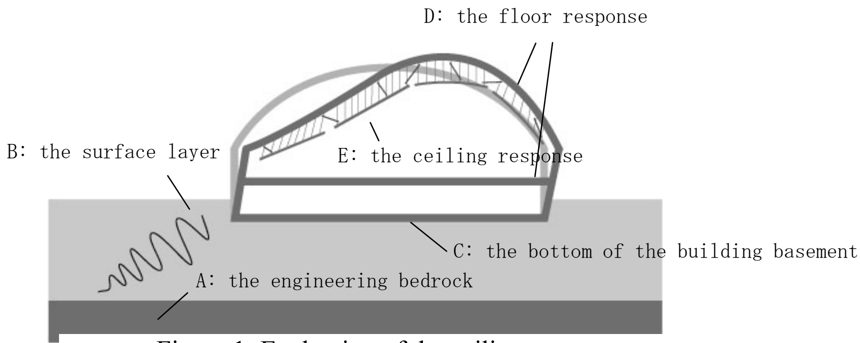


Figure 1: Evaluation of the ceiling response

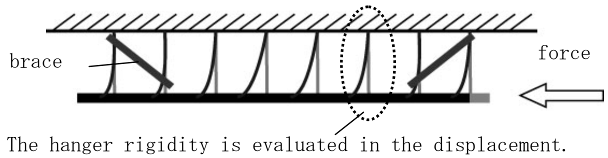
2.2. The fundamental natural period of the ceiling T

The fundamental natural period of the ceiling T used in ascertaining the design spectral coefficient and the lateral inertia force distribution factor must be determined in accordance with the following formula:

$$T = 2\pi\sqrt{\frac{ml}{mg + kl}} = 2\pi\sqrt{\frac{m}{mg/l + k}} = 2\pi\sqrt{\frac{m}{K}} \tag{3}$$

Where T=the fundamental natural period of the ceiling in seconds, m=the mass of the ceiling, l=the length of a pendulum, g=the gravity acceleration, k=the rigidity of the hanging bolt, and K=the equivalent rigidity considering the bending rigidity of the hunger in Fig.2.

$$\delta = \frac{L_b^{\ 3}}{3\times E_b \times I_b} + \frac{L_h^{\ 3}}{3\times E_h \times I_h} \tag{4}$$



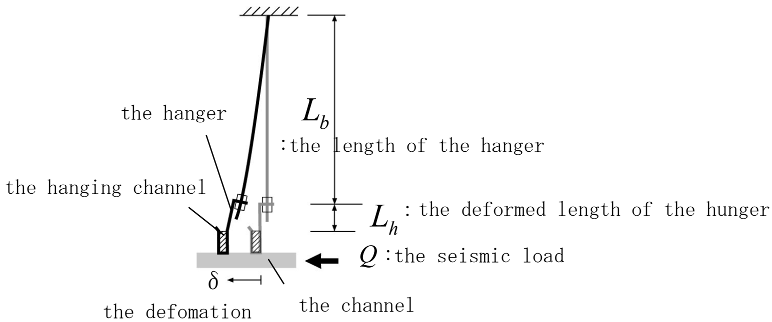


Figure 2: The rigidity of the ceiling

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3. Response of ceilings based on the vibration characteristics of spatial structures

The time history response analysis of the plane arch structures with the ceiling is carried out varying the each vibration characteristics. The seismic design coefficient β_H is evaluated in the roof of the maximum response acceleration of the roof and the ceiling.

3.1. Amplification characteristics at the ceiling board for each analysis model

In conventional earthquake-response analysis, the most common approaches to use waves observed either at the ground surface of a certain location, or at the basement or ground floor of a building as the input ground motion. The standard seismic waves as El-Centro NS, Taft EW, Hachinohe NS, and Center NS are used as input waves for the analysis. These records are normalized to be 50 cm/sec which is considered to be severe earthquake motion.

3.2. Analysis model

The elastic dynamic time history response analysis is carried out in order to investigate the amplification characteristics at the ceiling board using the analysis model shown in Fig.3. The analysis model deals with the arch rigid frame which has 70m in the span, 30m in the ridge height and 9m in the eaves height. The fundamental natural period of the arch structure results in 0.86 second as a result of the eigenvalue analysis. The ceiling has a symmetry system which is divided into 5 parts such as part A to E as shown in Fig.3. The Rayleigh damping is used for the analysis and the damping ratio is taken to be 2%. The Newmark β method is used for solving the vibration equation. As far as a boundary condition is concerned, the bottom of the column is set up to be a pin support.

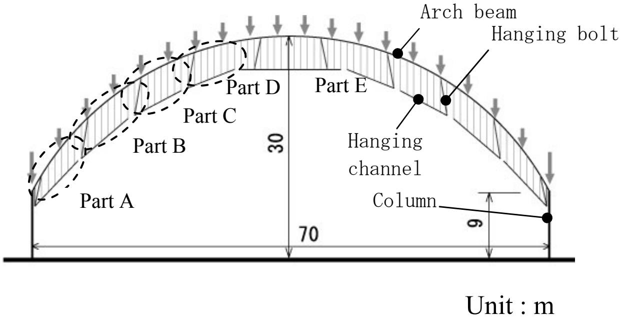

Figure 3: The arch rigid frame with the ceiling system

3.3. Amplification ratios at the ceiling level with respect to the fundamental natural period relationship between the ceiling and the arch frame structures

The amplification ratios of the each ceiling part A to B for the arch beam at the ridge are obtained by using the maximum earthquake response acceleration.

First, the ratios are shown in Fig.4 with respect to the length of the hanging bolt. The peak response acceleration of the ceiling with near 1.5m of the length at parts A, B and C which are set to be around the top of the column. It is noted that the ceiling depth around 1.5m is often used in this kind of the span length. This means that the large acceleration at the ceiling system is amplified by the resonance between the arch structure and the ceiling boards due to the seismic response.

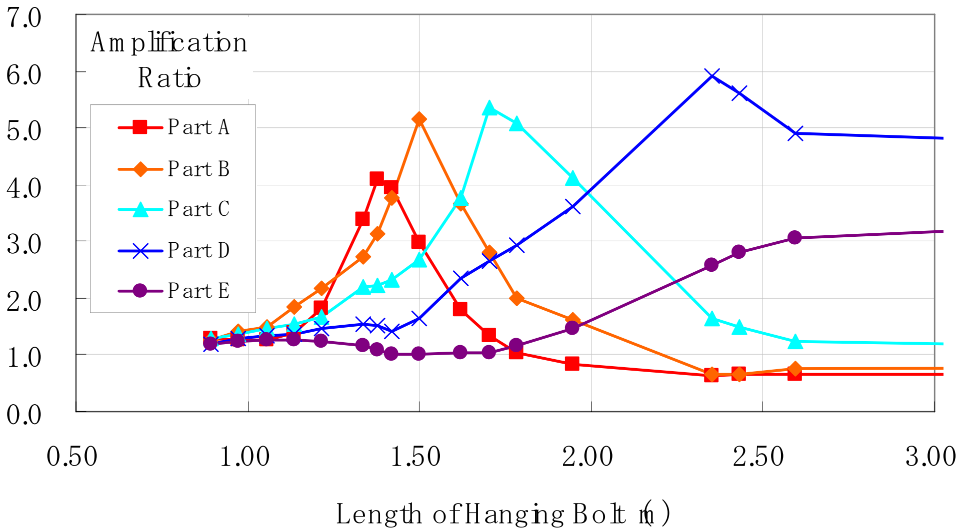

Figure 4: The amplification ratios of the each ceiling part A to B for the length of the hanging bolt

Next, The fundamental natural period of the each ceiling system T is calculated by using the equations (3) and (4) . The ratios are shown in Fig.5 with respect to the fundamental natural period of the ceiling system T. It is seen that the resonance phenomena appear near T=0.86 sec which is the fundamental natural period of the arch rigid frame. The ratios result in a range from 4 to 6. Consequently, the seismic design coefficient determined by ceiling amplification ratio β_H is taken to be a value in the range from 4 to 6.

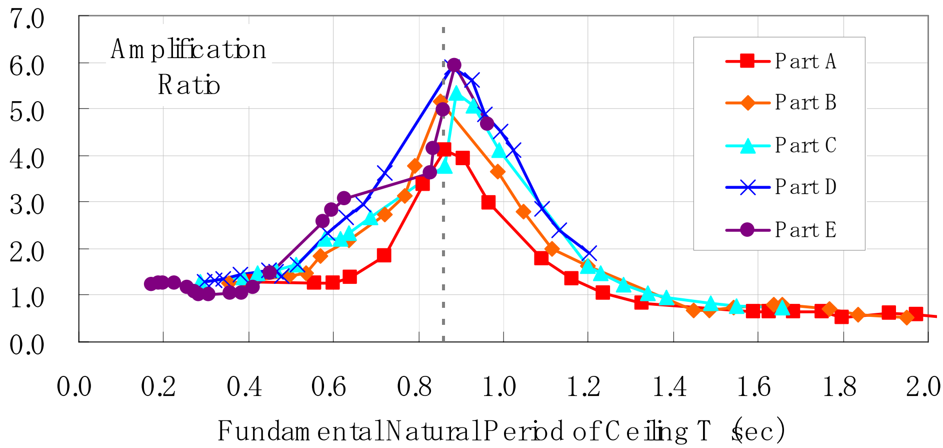

Figure 5: The amplification ratios of the each ceiling part A to B
for the fundamental natural period of the ceiling system T

4. Conclusions

The study deals with effects of the resonance between the arch rigid frame structures and the ceiling system on the seismic response.

In case that the fundamental natural period of the ceiling system T is close to the period of the arch structure, a large acceleration occurs in the range from 4 to 6 times greater than the maximum acceleration at the arch beam of the frame structure.

The seismic design coefficient determined by ceiling amplification ratio β_H is presented in this study. Although the seismic design coefficient β_H is derived by the analysis examples, this result may be useful in the actual design of the ceiling systems.

Acknowledgement

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