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Consideration on a design criteria for free solid model of Thick Wall and Floor Structure (TWFS)

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Abstract

In This paper, firstly, characters of TWFS for space and dynamics are showed. Secondly, explain Ds factor, which appears in the calculation of ultimate horizontal force, by energy method proposed by Akiyama. Then, formulate the relationship between Ds factor and inter story drift. Finally we evaluate TWFS Ds factor with the theory and data of structural design.

Keywords: Thick Wall and Floor Structure "TWFS", Continues System, Rahmen, Wall-Building, Ductility Reduction Factor, Cumulative Plastic Deformation, Inter Story Drift.

1. Introduction

Most of RC structures are designed as rahmen. The elements of this space are beam element of column and beam, therefore we can say rahmen is a discrete system. Continuous system of RC is more stable than discrete system and is adapted to its material character. Thick wall and floor structure "TWFS" is a continuous system as it made up of shell element of wall and slab. For this reason, TWFS have to evaluate as a continuous system and to set its design criteria, especially in a seismic design.

Meanwhile, the building standard law of Japan provides design criteria for RC rahmen from sustained load to seismic load. This paper aims to set TWFS design criteria which is based on RC rahmen.

2. Character of TWFS

TWFS is made up of slab and wall, therefore it has two different system for each direction. One way is wall-building system and the other is rahmen system. In this section, explain character of space and dynamics of TWFS.

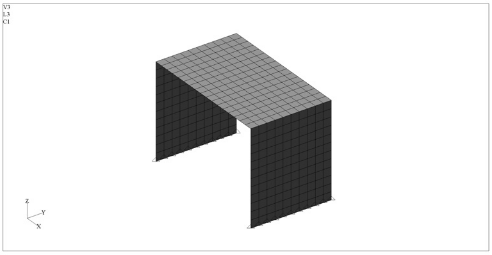


Figure 1: A model of TWFS

2.1. Spatial character of TWFS

TWFS which is a shell system comes from these demands of sosiety below,

・Low-rize and middle-rize housing need durability and seismic performance as RC wall-building.

・Having a good living space like RC rahmen.

・Make it possible to plan every ground line.

・Keep no column space for 15m span to be able to plan free.

As usual, the system of RC rahmen with walls has both character of rahmen and wall-building system, but it has much difficulty in planning.TWFS is baced on rahmen with wall with such demands.

2.2. Dynamically character of TWFS

In the structural design of TWFS, we have to analize as shell elements by finite element method. Here, to explain the resistant system, make a simple model of FEM which is made by MSC Nastran.

2.2.1.Dynamic system of TWFS in sustained load

In sustained load, TWFS transmits stress by bending moment of wall and slab.

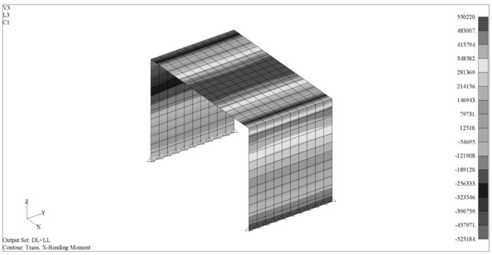


Figure 2: Analysis result of bending moment

2.2.2.Dynamic system of TWFS in seismic load

There are two different systems in seismic load for each direction. Fg.3 is wall-building direction. TWFS transmits stress by in-plane shear force.

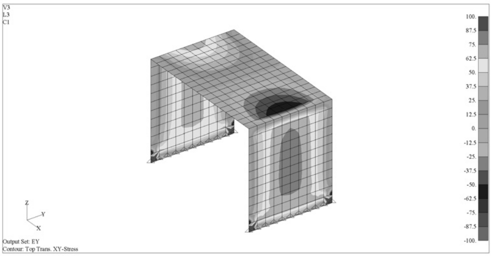


Figure 3: Analysis result of in-plane shear stress

Fg.4 is rahmen direction. TWFS transmits stress by bending moment of wall and slab like it counterpart of column and beam.

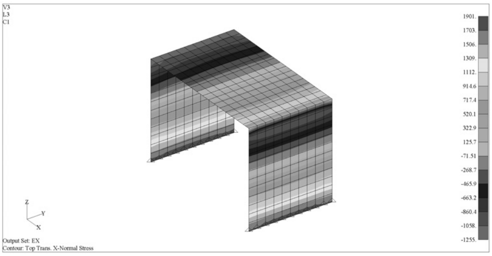


Figure 4: Analysis result of normal stress

3. Ultimate strength of TWFS in seismic design

3.1. Ductility reduction factor Ds

For a building which clears some conditions, the building standard law of Japan provides to calculate ultimate horizontal resistant force (“Qu”) over ultimate horizontal necessary force (“Qun”). The calculation of “Qun” is below.

$$Q_{un} = D_s F_{es} Q_{ud} \tag{*}$$

Where,

Q_{un} : Ultimate horizontal necessary force of each story

D_s : Ductility reduction factor

F_{es} : Calculated by the eccentricity factor and stiffness factor

Q_{ud} : Ultimate horizontal resistant force

The aim of setting up Ds factor is to set allowable elastoplastic deformation and failure type of a structure in an earthquake. Hence, to set Ds factor small means to allow big elastoplastic deformation and to expect energy absorption, the structure have to enduer its deformatin and to keep it energy absorption performance. Thus Ds factor is a reduction coefficient of ultimate horizontal resistant force with its elastoplastic deformation and performance of energy absorption.

3.2. General formulation for Ds factor

In this section, Ds factor is formulated by the energy method proposed by Akiyama, where the model is perfect elastoplasticity.

3.2.1. Concept of energy input

Fg shows, a model of one mass system of perfect elastoplasticity. Equation of vaibration of this system is below,

$$M\ddot{y} + C\dot{y} + F(y) = Fe \tag{1}$$

Where,

M : Total mass of a structure

C : Viscous damping factor

$F(y)$: Restoring force

Fe : Seismic force $= M\ddot{z}_0$

z_0 : Ground motion

y : Relative displacement

Figure 5: A model for one mass system of perfect elastoplasticity

Eq(2) is theresult of multiplying the both side of Eq(1) by $dy = \dot{y}dt$, then integrate the whole time of an earthquake.

$$M\int_0^{t_0} \ddot{y}\dot{y}dt + C\int_0^{t_0} \dot{y}^2 dt + \int_0^{t_0} F(y)\dot{y}dt = \int_0^{t_0} Fe\dot{y}dt \tag{2}$$

Describe Eq(2) as follows

$$W_P + W_e + W_h = E \tag{3}$$

Where,

W_P : Energy absorption due to plastic deformation of a structure

W_e : Elastic vibration energy

W_h : Energy absorption due to damping

E : Total energy input exerted by an earthquake

The range of W_e is

$$0 \le W_e \le \frac{Q_y \delta_y}{2} \tag{4}$$

Where,

Q_y : Yield force

δ_y : Yield displacement

Transmit W_h to the other side

$$W_P + W_e = E - W_h = E_D = \frac{M{V_D}^2}{2} \tag{5}$$

Where,

V_D : Equivalent velocity

3.2.2. Formulation for Ds factor

W_e can be expressd as

$$W_e = \frac{Q_y \delta_y}{2} = \frac{{\alpha_e}^2}{2} \cdot \frac{Mg^2 T^2}{4\pi^2} \tag{6}$$

Where,

α_e : Yield shere coefficent

g : Acceleration of gravity

T : Period of a structure

Meanwhile, energy absorption due to elastoplastic deformation can be expressd as

$$W_p + W_e = \alpha^2 (\frac{1}{2} + \eta) \cdot \frac{Mg^2 T^2}{4\pi^2} \tag{7}$$

Where,

η : Cumulative plastic deformation

If we assume Eq(6) is equal to Eq(7), there is Eq(8)

$$\alpha = \frac{\alpha_e}{\sqrt{2\eta + 1}} \tag{8}$$

Eq(8) means that the areas ,in Fg6 , of hatching is equal.

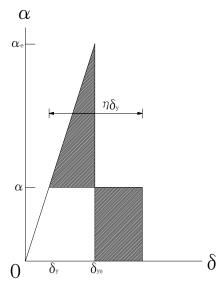


Figure 6: Energy absorption

The size of cumulative plastic deformation of positive and negative direction is equal within the perfect elastoplasticity. The relationship between average plasticity rate $\overline{\mu}$ and average cumulative plastic deformation $\overline{\eta}$ is $\overline{\eta} = 2\overline{\mu}$. Thus, $\eta = 2\overline{\eta} = 4\overline{\mu}$

$$\alpha = \frac{\alpha_e}{\sqrt{8\overline{\mu} + 1}} \tag{9}$$

Where, Eq (*) gives Ds factor as the reduction ratio of shear coefficient which is attribute to energy absorption due to elastic plastic deformation.
Therfore,

$$Ds = \frac{\alpha}{\alpha_e} = \frac{1}{\sqrt{8\overline{\mu} + 1}} \tag{10}$$

Eq(11) is approved

$$\overline{\mu} \le \mu_{\max} = \frac{\delta_{\max} - \delta_y}{\delta_y} \tag{11}$$

Inter-story drift is $\theta = \dfrac{\delta}{h}$, therefore Eq(12) is expressed as follows.

$$Ds = \frac{1}{\sqrt{8\overline{\mu}+1}} \geq \frac{1}{\sqrt{8\dfrac{\theta_{\max}-\theta_y}{\theta_y}+1}} = \sqrt{\frac{\theta_y}{8\theta_{\max}-7\theta_y}} \tag{12}$$

3.3.The relationship between max inter story drift and Ds factor

Inter story drift of yield time for a structure $h = 350cm$ is about

Rahmen : $\theta_y = \dfrac{1}{500}$

Wall-building : $\theta_y = \dfrac{1}{4950}$

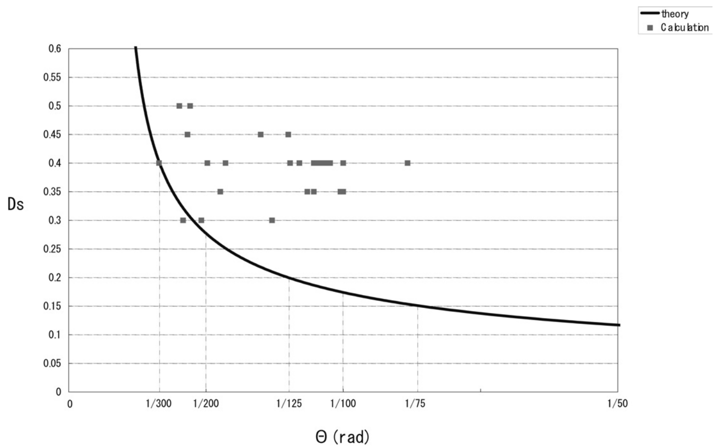


Figure 7: Rahmen direction of Ds factor-inter story drift

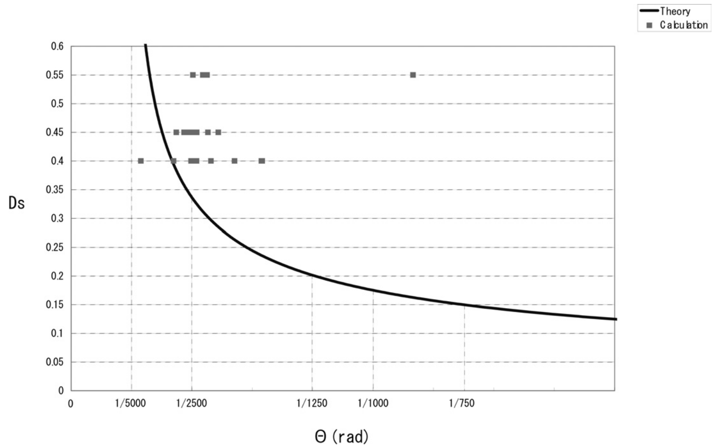
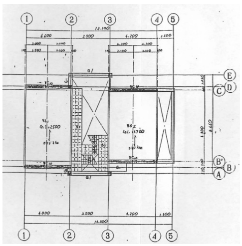
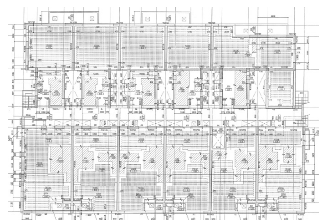


Figure 8: Wall-building direction of Ds factor-inter story drift

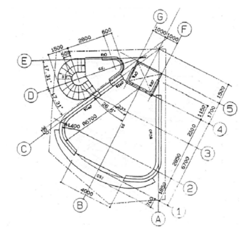
Fg7,8 is the result of Ds factor-inter story drift of rahmen direction and wall-building direction of TWFS. Full line is the result of Eq(12) and square is the automatic caluculation result of Ds-inter story drift by load incremental analysis. The caluculation used the program of US2 and SS2 by Union system. Eq(12) sugests that the theory is lower limit of Ds factor. Plans of structures caluculated are follows,



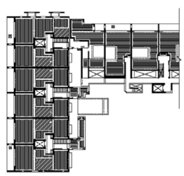
Mint House



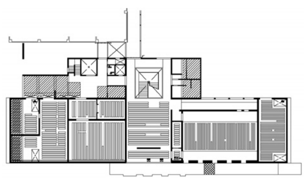
D'Granse Mita



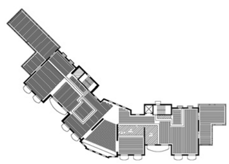
Art Silo



Daizawa Park House



Hansen's disease resource center



Yokohama Bay Side Marina

Sibata High school

4. Conclusion

In this paper, we sort out a character of continues system for TWFS, then suggest the relationship between Ds factor and inter story drift. Finally, we find out Eq(12) gives us the lower limit of Ds factor in a inter story drift.

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