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.
2.1. Spatial character of TWFS

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

- Low-rise and middle-rise 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 based on rahmen with wall with such demands.

2.2. Dynamically character of TWFS

In the structural design of TWFS, we have to analyze 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.

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

![Figure 3: Analysis result of in-plane shear stress](image)

Fig. 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](image)

### 3. Ultimate strength of TWFS in seismic design

#### 3.1. Ductility reduction factor $D_s$

For a building which clears some conditions, the building standard law of Japan provides to calculate ultimate horizontal resistant force (“$Q_u$”) over ultimate horizontal necessary force (“$Q_{un}$”). The calculation of “$Q_{un}$” is below.

$$Q_{un} = D_s F_{es} Q_{udf}$$

(*)

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
$Q_{ul}$ : Ultimate horizontal resistant force

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

3.2. General formulation for $D_s$ factor

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

3.2.1. Concept of energy input

Equation of vibration of this system is below,

$$M\ddot{y} + C\dot{y} + F(y) = F_e$$

(1)

Where,

- $M$ : Total mass of a structure
- $C$ : Viscous damping factor
- $F(y)$ : Restoring force
- $F_e$ : Seismic force $= Mz_0$
- $z_0$ : Ground motion
- $y$ : Relative displacement

Eq(2) is the result of multiplying the both side of Eq(1) by $\dot{y}dt$, then integrate the whole time of an earthquake.
\begin{equation}
M \int_0^t \ddot{y} dt + C \int_0^t \dot{y}^2 dt + \int_0^t F(y) \dot{y} dt = \int_0^t F(y) dt
\end{equation}

Describe Eq(2) as follows

\begin{equation}
W_P + W_e + W_h = E
\end{equation}

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

\begin{equation}
0 \leq W_e \leq Q_y \delta_y
\end{equation}

Where,

- \(Q_y\): Yield force
- \(\delta_y\): Yield displacement

Transmit \(W_h\) to the other side

\begin{equation}
W_P + W_e = E - W_h = E_D = \frac{M V_D^2}{2}
\end{equation}

Where,

- \(V_D\): Equivalent velocity

3.2.2. Formulation for Ds factor

\(W_e\) can be expressed as

\begin{equation}
W_e = \frac{Q_y \delta_y}{2} = \frac{\alpha_s^2}{2} \frac{M g^2 T^2}{4 \pi^2}
\end{equation}

Where,

- \(\alpha_s\): Yield shear coefficient
- \(g\): Acceleration of gravity
- \(T\): Period of a structure

Meanwhile, energy absorption due to elastoplastic deformation can be expressed as
\[
W_p + W_c = \alpha^2 \left(\frac{1}{2} + \eta\right) \frac{MgT^2}{4\pi^2}
\]

Where,
\[
\eta : \text{Cumulative plastic deformation}
\]

If we assume Eq(6) is equal to Eq(7), there is Eq(8)
\[
\alpha = \frac{\alpha_e}{\sqrt{2\eta + 1}}
\]

Eq(8) means that the areas, in Fig6, of hatching is equal.

![Figure 6: Energy absorption](image)

The size of cumulative plastic deformation of positive and negative direction is equal within the perfect elastoplasticity. The relationship between average plasticity rate \( \mu \) and average cumulative plastic deformation \( \eta \) is \( \eta = 2\bar{\eta} = 4\bar{\mu} \). Thus,
\[
\alpha = \frac{\alpha_e}{\sqrt{8\bar{\mu} + 1}}
\]

Where, Eq (*) gives Ds factor as the reduction ratio of shear coefficient which is attribute to energy absorption due to elastic plastic deformation. Therefore,
\[
Ds = \frac{\alpha}{\alpha_e} = \frac{1}{\sqrt{8\bar{\mu} + 1}}
\]

Eq(11) is approved
\[
\bar{\mu} \leq \mu_{min} = \frac{\delta_{min} - \delta_r}{\delta_r}
\]

Inter-story drift is \( \theta = \frac{\delta}{h} \), therefore Eq(12) is expressed as follows.
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: $\theta_y = \frac{1}{500}$

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

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 calculation result of Ds-inter story drift by load incremental analysis. The calculation used the program of US2 and SS2 by Union system. Eq(12) suggests that the theory is lower limit of Ds factor. Plans of structures calculated are follows,
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.

References