STUDY ON ARRANGEMENTS OF ASEISMATIC ELEMENTS

By SUKENOBU TANI*

1. Introduction.

This paper is the report on stiffness and lateral force distribution in the frame with aseismatic elements (bracings or walls). It has been well known that aseismatic bracings and walls to arrange in the frame are very effective against earthquakes. However, we have few studied the subjects on the reasonable arrangement of aseismatic elements. Aseismatic elements to be arrange continuously to a vertical direction have been recomended customarily. But, this arrangement has some weak points as follow; Structural planning is restricted, and in addition to, lateral force distribution of aseismatic elements decreases at the higher portion of the structure. Sometimes, contrary effect come out.

This paper showes that dispersive arrangements of aseismatic elements at each story increase freedom of planning and make uniform lateral force distribution at each story, so that we may rationalize the arrangement of aseismatic elements.

In the first, we will discuss theoretically stiffness and lateral force distribution on the continuous arrangement which have been adopted customarily, and in the next, we will discuss those of the dispersive arrangements and indicate the results of the experiment used the steel model. Lastly, we will discuss the character of the arbitrary arrangements by means of Stress-Controlled Calculation and compare the above results with the experiment used the achlilite model.

2. Stiffness and Lateral Force Distribution on Continuous Arrangement of Aseismatic Elements.

Stiffness and lateral force distribution on the continuous arrangement in elastic range will be required by finite differences and be discussed.

(2.1) Stiffness and Lateral Force Distribution on Continuous Arrangement of Bracings.

Consider the structure that is the symmetric plan, as shown in Fig 1. It is assumed that the each of frames is connected with rigid floors at each story. The elevation of the frame is shown in Fig 2. In A and D frame, bracings are arranged continuously, and the other hand, B and C frame are open frames. The assumption is that the axial force acting on the pairs of column in A(D) frame is equal to

* Assistant Professor, School of Science and Engineering of Waseda University, Tokyo, Japan.

each other in the absolute value and contrary in the sign.

When the angle of deflection of column caused by the bending deformation at the n-th story is denoted by ${}_mR_{An}$ and that of beam is ${}_mR'_{An}$, ${}_mR_{An}$ is equal to ${}_mR'_{An}$. The relation between the deformation and the stress at n-th story is expressed as follow,

$$ {}_mR_{An} - {}_mR_{A(n-1)} = \frac{2M_{An}h_n}{A_{An}E\ell^2} \tag{1} $$

where, M_{An} = bending moment at the n-th story in A frame
A_{An} = column area at the n-th story in A frame
E = modulus of elasticity
h_n = story height at the n-th story

If the shearing force at the n-th story in A frame is denoted by Q_{An}.

$$ \left.\begin{aligned} M_{An} &= \sum_{n}^{s} Q_{Ai}h_i \\ M_{A(n-1)} &= \sum_{n-1}^{s} Q_{Ai}h_i \end{aligned}\right\} \tag{2} $$

When h_n is the same at each story, h_n may be replaced by h.

Substituting Eqs. (2) in Eq.(1)

$$ {}_mR_{An} - {}_mR_{A(n-1)} = \frac{2h^2}{A_{An}E\ell^2}\sum_{n}^{s} Q_{An} \tag{3} $$

similarly,

$$ {}_mR_{A(n-1)} - {}_mR_{A(n-2)} = \frac{2h^2}{A_{A(n-1)}E\ell^2}\sum_{n-1}^{s} Q_A \tag{4} $$

when A_{An} is the same at each story, it is replaced by A. Subtrating Eq.(3) to Eq.(4), if (n-1) is replaced by n,

$$ {}_mR_{A(n+1)} - 2\,{}_mR_{An} + {}_mR_{A(n-1)} = -{}_mK_A Q_{An} \tag{5} $$

where, ${}_mK_A = \frac{2h^2}{AE\ell^2}$ (bending softness coefficient) (6)

When the beam is much larger than column on stiffness, the shearing deformation in A frame is,

$$ {}_sR_{An} = \frac{h^2}{4EI_A\left(6 + \frac{A_d h^3}{4I_A L}\cos^2\theta\right)} Q_{An} \tag{7} $$

where, ${}_sR_{An}$ = shearing deflection angle at the n-th story in A frame.
A_d = bracing area in A frame
I_A = moment of inertia of column in A frame
L = length of bracing
θ = inclination of bracing

denoting ${}_sK_A$ as follow,

$$ {}_sK_A = \frac{h^2}{4EI_A\left(6 + \frac{A_d h^3}{4I_A L}\cos^2\theta\right)} \quad \text{(shearing softness coefficient)} \tag{8} $$

Substituting Eq.(8) in Eq.(7)

$$ {}_sR_{An} = {}_sK_A Q_{An} \tag{7a} $$

Then, as the total deformation is the sum of the bend-

ing and the shearing deformation, the below expression is given,

$$ {}_mR_{An} + {}_sR_{An} = R_{An} \tag{9} $$

similarly, in B frame

$$ {}_mR_{Bn} + {}_sR_{Bn} = R_{Bn} \tag{10} $$

If $R_{An} = R_{Bn} = R_n$, combining Eq.(5) and Eq.(7a),

$$ R_{(n+1)} - 2R_n - R_{(n-1)} = {}_sK_A Q_{A(n+1)} - ({}_mK_A + 2{}_sK_A) Q_{An} + {}_sK_A Q_{A(n-1)} \tag{12} $$

Since B frame is open, the deformation of B frame may be considered mainly the shearing deformation, so the following expression is given,

$$ {}_sR_{Bn} = R_{Bn} = R_n = \frac{h^2}{24EI_B} Q_{Bn} \tag{13} $$

where, I_B = moment of inertia of column in B frame.

${}_sK_B$ is denoted as follow,

$$ {}_sK_B = \frac{h^2}{24EI_B} \tag{14} $$

Substituting Eq.(14) in Eq.(13)

$$ R_n = {}_sK_B Q_{Bn} \tag{13a} $$

Combining Eq.(5) and Eq.(7a), but Eq.(15) is given by using Eq.(17)

$$ R_{(n+1)} - \gamma R_n + R_{(n-1)} = (2A-B)(S+1)P - (2A-B)Pn \tag{15} $$

where,

$$ \left.\begin{aligned} p &= \frac{2 + ({}_mK_A + 2{}_sK_A)\frac{1}{{}_sK_B}}{1 + \frac{{}_sK_A}{{}_sK_B}} \\ A &= \frac{{}_sK_A}{1 + \frac{{}_sK_A}{{}_sK_B}}, \qquad B = \frac{{}_mK_A + 2{}_sK_A}{1 + \frac{{}_sK_A}{{}_sK_B}} \end{aligned}\right\} \tag{16} $$

$$ Q_{An} + Q_{Bn} = Q_n = (S - n + 1)P \tag{17} $$

The solution of Eq.(15) is,

$$ R_n = C_1 \sinh\varphi \cdot n + C_2 \cosh\varphi \cdot n + \frac{2A-B}{2-p}(S+1-n)P \tag{18} $$

$$ \left(\because \cosh\varphi = \frac{p}{2}\right) $$

where, C_1 and C_2 are constant to be determined by boundary conditions. In the boundary conditions that is the fixed end at the base of the 1st story and is the framed structure of the S-th story, C_1 and C_2 are given as below,

$$ \left.\begin{aligned} C_1 &= \frac{U_1(p'\cosh S\varphi - \cosh(S-1)\varphi) - U_2(\cosh 2\varphi - p\cosh\varphi)}{(\sinh 2\varphi - p\sinh\varphi)(p'\cosh S\varphi - \cosh(S-1)\varphi) - (\cosh 2\varphi - p\cosh\varphi)(p'\sinh S\varphi - \sinh(S-1)\varphi)} \\ C_2 &= \frac{-U_1(p'\sinh S\varphi - \sinh(S-1)\varphi) + U_2(\sinh 2\varphi - p\sinh\varphi)}{(\sinh 2\varphi - p\sinh\varphi)(p'\cosh S\varphi - \cosh(S-1)\varphi) - (\cosh 2\varphi - p\cosh\varphi)(p'\sinh S\varphi - \sinh(S-1)\varphi)} \end{aligned}\right\} \tag{19} $$

where,

$$ \left.\begin{aligned} U_1 &= \left[(S-1)A - SB - \frac{2A-B}{2-p}\{(S-1) - \gamma S\}\right] P \\ U_2 &= \left[B' - 2A - \frac{2A-B}{2-p}(p'-2)\right] P \\ p' &= \frac{1 + ({}_mK_A + {}_sK_A)\frac{1}{{}_sK_B}}{1 + \frac{{}_sK_A}{{}_sK_B}}, \qquad B' = \frac{{}_mK_A + {}_sK_B}{1 + \frac{{}_sK_A}{{}_sK_B}} \end{aligned}\right\} \tag{20} $$

If R_n has been required, Q_{Bn} may be obtained. Considering $Q_{An} = Q_n - Q_{Bn}$, lateral force distribution ratio on A frame against B frame may be obtained as follow,

$$ D_n = \frac{Q_{An}}{Q_{Bn}} \tag{21} $$

As the results of numerical calculation, the following character is indicated.

1. The higher the story became, the smaller lateral force distribution ratio became,

2. The distribution ratio took a negative value at the higher story of the structure which had 9 or 10 stories.

3. The fewer the story order became, the larger the distribution ratio at 1st story became.

4. At the story of the same order from the top, the fewer the story order became, the larger the distribution ratio became.

5. At the lower story, the shearing deformation was large, and at the higher story, the bending deformation was large. (see, Fig. 4,5,6,7).

(2.2) Stiffness and Lateral Force Distribution on Continuous Arrangement of Aseismatic Walls.

Same as in the bracings, we may obtain the equation to give R_n on this case. In A frame, instead of A_n that is the column area, the equivalent column area A_n' is adopted and is given approximately as follow,

$$A_n' = A_{An} + \frac{A_{wn}}{6} \tag{22}$$

where, A_{wn} = horizontal sectional area of the aseismatic wall ($t_a \cdot \ell$), consequently, the bending softness coefficient ${}_mK_A$ is,

$${}_mK_A = \frac{2h^2}{A'E\ell^2} \tag{23}$$

also, the shearing softness coefficient ${}_sK_A$ is,

$${}_sK_A = \frac{2k(1-\nu)}{E\,A_{wn}} \tag{24}$$

where, ν = Poisson's ratio

k = constant to be determined by the shape of the section.

Stiffness and lateral force distribution were the same results that had been obtained in the bracing. (see Fig. 8)

3. Stiffness and Lateral Force Distribution on Dispersive Arrangement of Aseismatic Elements.

(3.1) Calculation of Lateral Force Distribution Ratio by means of Simultanous Equation.

Consider the general aseismatic bracing's arrangement as shown in Fig. 9. The shearing Force acting at the n-th story in A frame is denoted by Q_{An}, and at the n-th story in B frame is denoted by Q_{Bn}, where,

$$Q_{An} + Q_{Bn} = Q_n \tag{25}$$

The relation between the angle of deflection caused by the bending deformation and the shearing force at the n-th story in A frame is

$${}_mR_{An} - {}_mR_{A(n-1)} = {}_mK_{An} \sum_n^s Q_{Ai} \tag{26}$$

where, ${}_mK_{An}$ = the bending softness at the n-th story in A frame

$_mR_{An}$ = the angle of deflection caused by bending deformation at the n-th story in A-frame

Similarly, at the n-th story in B frame

$$_mR_{Bn} - {}_mR_{B(n-1)} = {}_mK_{Bn} \sum_n^s Q_{Bi} \tag{27}$$

where, $_mK_{Bn}$ = the bending softness at the n-th story in B frame

$_mR_{Bn}$ = the angle of deflection caused by bending deformation at the n-th story in B frame.

Also, the relation between the angle of deflection caused by the shearing deformation and the shearing force at the n-th story in A frame is given by the following equation,

$$_sR_{An} = {}_sK_{An} \cdot Q_{An} \tag{28}$$

where, $_sK_{An}$ = the shearing softness at the n-th story in A frame

$_sR_{An}$ = the angle of deflection caused by the shearing deformation at the n-th story in A frame

Similarly, at the n-th story in B frame.

$$_sR_{Bn} = {}_sK_{Bn} \cdot Q_{Bn} \tag{29}$$

The total angle of deflection is obtained by summing the angle of deflection caused by the bending deformation and the shearing deformation, and that is

$$_mR_{An} + {}_sR_{An} = R_{An} \tag{30}$$

and, $$_mR_{Bn} + {}_sR_{Bn} = R_{Bn} \tag{31}$$

then, as, in Eq.(30) and (31), $R_{An} + R_{Bn}$

$$_mR_{An} + {}_sR_{An} = {}_mR_{Bn} + {}_sR_{Bn} \tag{32}$$

$_mR_{A1}, {}_mR_{A2}, \text{---------}, {}_mR_{An}, \text{---}, {}_mR_{AS}$ can be required from Eq.(26). Similarly, $_mR_{B1}, {}_mR_{B2}, \text{--------}, {}_mR_{Bn}, \text{---}, {}_mR_{BS}$ are required from Eq. (27). Substituting the value of them, Eq.(28) and Eq.(29) in Eq.(32), the following equation at the n-th story may be obtained,

$$\begin{aligned}
&\left(\sum_1^n {}_mK_{Ai} + \sum_1^n {}_mK_{Bi}\right) Q_{AS} + \left(\sum_1^n {}_mK_{Ai} + \sum_1^n {}_mK_{Bi}\right) Q_{A(S-1)} + \text{--------} \\
&+ \left(\sum_1^n {}_mK_{Ai} + \sum_1^n {}_mK_{Bi}\right) Q_{A(n+1)} + \left\{\left(\sum_1^n {}_mK_{Ai} + \sum_1^n {}_mK_{Bi}\right) + ({}_sK_{An} + {}_sK_{Bn})\right\} Q_{An} \\
&+ \left(\sum_1^{n-1} {}_mK_{Ai} + \sum_1^{n-1} {}_mK_{Bi}\right) Q_{A(n-1)} + \text{----------} + ({}_mK_{A1} + {}_mK_{B1}) Q_{A1} \\
&= \left(\sum_1^n {}_mK_{Bi}\right) Q_S + \left(\sum_1^n {}_mK_{Bi}\right) Q_{(S-1)} + \text{---------} + \left(\sum_1^n {}_mK_{Bi}\right) Q_{(n+1)} \\
&+ \left(\sum_1^n {}_mK_{Bi} + {}_sK_{Bn}\right) Q_n + \left(\sum_1^{n-1} {}_mK_{Bi}\right) Q_{(n-1)} + \text{----------} + \left(\sum_1^2 {}_mK_{Bi}\right) Q_2 \\
&+ ({}_mK_{B1}) Q_1
\end{aligned} \tag{33}$$

Consequently, the shearing force at each story in A and B frame may be required from setting up the simultaneous equations to be equal to the story orders in a number, and then lateral force distribution ratio may be determined from Eq.(21).

As the results of numerical calculation, the following facts is indicated.

1. In the continuous arrangement of aseismatic elements,

the lateral force distribution ratio was smaller than what considered only the shearing deformation at the same story on the higher portion. In the structure that had many stories, the distribution ratio at the higher story took a negative value.

2. When aseismatic elements was arranged dispersively at one story at least, the distribution ratio at each story was larger than that at the same story on the above condition 1. But, the parts of continuous arrangement kept the the character of itself.

3. In uniformly dispersive arrangements of aseismatic elements, the distribution ratio at each story was nearly equal to what considered only the shearing deformation. (see Fig. 9,10,11,12,13)

(3.2) Comparison of Stiffness on Arrangements with Steel Model.

The stiffness may be compared on arrangements of aseismatic bracings with the model of a steel framed structure in which is inserted bracings, as shown in Fig. 14,15. The equivalent external force is given parallel to the ridge direction at each story, so that the following facts is indicated.

1. In the continuous arrangement of aseismatic bracings, the deformation is the largest of all, that is to say, the stiffness is the smallest.

2. In the uniformly dispersive arrangement of aseismatic bracings, the deformation is the smallest, that is to say, the stiffness is the largest.

3. In the arrangements which exist between 1 and 2, the deformation exists between 1 and 2, so that the stiffness exists between 1 and 2. (see Fig. 16)

4. Stiffness and Lateral Force Distribution on Arbitrary Arrangement of Aseismatic Elements by means of Stress-Controlled Calculation.

In the case that aseismatic elements are arranged dispersively, the determination of lateral force distribution is required from setting up the simultaneous equations about the each of arrangements as discussed in the former chapter. But, that method is difficult, and then the practical method will be introduced in this chapter. This is the method to require lateral force distribution from being aware of both the stress of aseismatic elements and columns on arbitrary arrangements of aseismatic elements. This method is styled "Stress-Controlled Calculation".

Stress-Controlled Calculation may express the bending deformations on arrangements of aseismatic elements with the axial stress of the each of columns, and their shearing deformations are expressed with the axial stress of aseismatic elements. Then, observing the each stress discribed in the above, the calculation may be put gradually foreward. In this method, basing the aseismatic elements and the shear-

ing stiffness of general frames, lateral force distribution of arbitrary arrangements may be required by multiplying the correct coefficients caused by the relative bending deformation.

Consequently, to determine lateral force distribution is comparatively easy in any arrangement. Also, through the medium of the stress of the structural elements, the unreasonable stress condition may be discovered on a way of the calculation, so that, reasonable lateral force distribution may be determined by controlling the stress with the alteration of the cross section. According to this method, to determine a cross section is be possible, too, if the distribution has been known.

(4.1) Stiffness and Lateral Force Distribution by means of Stress-Controlled Calculation on Arbitrary Arrangement of Bracings in Elastic or Plastic Range.

In this chapter, we will derive the fundamental expression to determine lateral force distribution on aseismatic bracings which are symmetric arrangement in elastic or plastic range. Now, when aseismatic bracings to be arranged at the n-th story in A frame have reached the yield stress σ_0, and exist in the perfectly plastic range, the angle of deflection based on the shearing deformation is, (Fig. 17)

$$ {}_sR_{An} = K_{on} \cdot {}_sR_0 = K_{on} \cdot \frac{2\sigma_0}{E \sin 2\theta_n} \tag{34} $$

where, $$ K_{on} = \frac{{}_sR_{An}}{{}_sR_0} \tag{35} $$

Then, the total angle of deflection at the n-th story in A or B frame, that is R_{An} or R_{Bn}, may be given as below,

$$ R_{An} = \left(\frac{2\sigma_0}{E \sin 2Q_n}\right) K_{on} + \frac{2}{E\ell} \sum_{i=1}^{n} \sigma_{Ai} \cdot h_i \tag{36} $$

$$ R_{Bn} = \frac{h_n^2}{2EA_{Bn}^2} Q_{Bn} + \frac{2}{E\ell} \sum_{i=1}^{n} \sigma_{Bi} \cdot h_i \tag{37} $$

where, $R_{An} = R_{Bn}$ and if $A_{An} = A_{Bn} = A_n$,

$$ \left\{\left(\frac{2\sigma_0}{\sin 2\theta_n}\right) K_{on} + \frac{2}{\ell} \sum_{i=1}^{n} (\sigma_{Ai} - \sigma_{Bi}) h_i\right\} A_n^2 = \frac{h_n^2}{2} Q_{Bn} \tag{38} $$

Then, Eq.(38) gives the following equation for lateral force distribution at the n-th story D_n,

$$ D_n = \frac{Q_{An}}{Q_{Bn}} = \frac{{}_sK_{Bn}}{{}_sK_{An}} \cdot \mu_{(AB)n} = \frac{{}_sD_{An}}{{}_sD_{Bn}} \mu_{(AB)n} \tag{39} $$

where, ${}_sK_{An}$ = shearing softness coefficient at the n-th story in A frame $\left(\frac{1}{{}_sD_{An}}\right)$

${}_sK_{Bn}$ = shearing softness coefficient at the n-th story in B frame $\left(\frac{1}{{}_sD_{Bn}}\right)$

${}_sD_{An}$ = lateral force distribution coefficient of shearing deformation at the n-th story in A frame

${}_sD_{Bn}$ = lateral force distribution coefficient of shearing deformation at the n-th story in B frame.

$\mu_{(AB)n}$ = the correct coefficient caused by the relative bending deformation of lateral force distribution of B frame for that of A frame at the n-th story.

where, $\mu_{(AB)n}$ is given as below,

$$\mu_{(AB)n} = \frac{1}{\left[K_{on} + \frac{\sin 2\alpha_n}{\ell} \cdot \frac{\sum_{i=1}^{n}(\sigma_{Ai} - \sigma_{Bi})h_i}{\sigma_o}\right]} \tag{40}$$

When the axial stress of the aseismatic bracings at the n-th story is denoted by σ_{dn}, the following expressions is obtained,

$$\left.\begin{array}{l} \text{if } \sigma_{dn} \leq \sigma_o \text{ (in elastic range)} \text{ -------- } \sigma_o = \sigma_{dn},\ K_{on} = 1 \\ \text{if } \sigma_{dn} > \sigma_o \text{ (in plastic range)} \text{ -------- } \sigma_{dn} = \sigma_o,\ K_o = \frac{{}_sR_{An}}{{}_sR_o} > 1 \end{array}\right\} \tag{41}$$

in the above, if $h_i = h$, K_{on} is

$$K_{on} = \frac{{}_sR_{An}}{{}_sR_o} = \frac{2\sin^2\alpha}{\sigma_o}\left[\frac{\ell h}{2A_n}\left(\frac{Q_{Bn}}{2A_n}\right) - \sum_{i=1}^{n}(\sigma_{Ai} - \sigma_{Bi})\right] \tag{42}$$

With the above way, lateral force distribution of bracings in elastic or plastic range may be required. That is to say, when $\mu_{(AB)n} = 1$ is assumed, the 1st approximate value of D_n may be given from Eq.(40). The distribution is obtained by repeating the similar calculation. Next, we derive the fundamental expression to determine the distribution on aseismatic elements which are asymmetric arrangement.

In Fig. 18, the center of rotation is a point O. The distance between that point and the each of A,B,C,D,1,2, at the n-th story is denoted by X_{An}, X_{Bn}, X_{Cn}, X_{Dn}, Y_{1n}, Y_{2n}. The relation between the total angle of deflection R_{An} and R_{Bn} at the n-th story in A,B frame is shown below,

$$R_{An} = R_{Bn}\left(\frac{X_{An}}{X_{Bn}}\right) = R_{Bn} \cdot X_{(AB)n} \tag{43}$$

then, when the bracings which arrange at the n-th story in A,B frame is in plastic range, R_{An} and R_{Bn} are shown generally below,

$$R_{An} = {}_sK_{An} \cdot Q_{An} \cdot K_{on} - \frac{2}{E\ell}\sum_{i=1}^{n}\sigma_{Ai} h_i \tag{44}$$

$$R_{Bn} = {}_sK_{Bn} \cdot Q_{Bn} + \frac{2}{E\ell}\sum_{i=1}^{n}\sigma_{Bi} h_i \tag{45}$$

Substituting Eq.(44) and Eq.(45) in Eq. (43), lateral force distribution $D_{(AB)n}$ is given below,

$$\begin{aligned} D_{(AB)n} &= \frac{Q_{An}}{Q_{Bn}} = \frac{{}_sD_{An}}{{}_sD_{Bn}}\mu_{(AB)n} = \frac{{}_sD_{An}}{{}_sD_{Bn}} \cdot X_{(AB)n}\,\mu'_{(AB)n} \\ &= D'_{(AB)n}\,X_{(AB)n} \end{aligned} \tag{46}$$

where,

$$D'_{(AB)n} = \frac{{}_sD_{An}}{{}_sD_{Bn}}\mu'_{(AB)n}$$

$$\mu'_{(AB)n} = \frac{1}{\left[K_{on} + \frac{2\,{}_sD_{An}}{E\ell}\left\{\frac{\sum_{i=1}^{n}\sigma_{Ai}h_i - \left(\sum_{i=1}^{n}\sigma_{Bi}h_i\right)X_{(AB)n}}{Q_{An}}\right\}\right]} \tag{47}$$

then, K_{on} and $X_{(AB)n}$ are given as below.

$$K_{on}=\left[\frac{{}_sD_{An}}{{}_sD_{Bn}}X_{(AB)n}\cdot\left(\frac{Q_{Bn}}{Q_{An}}\right)-\frac{2\,{}_sD_{An}}{E\ell}\left\{\frac{\sum_{i=1}^{n}\sigma_{Ai}h_i-\left(\sum_{i=1}^{n}\sigma_{Bi}h_i\right)X_{(AB)n}}{Q_{An}}\right\}\right] \tag{48}$$

$$X_{Bn}=\left[\frac{3D'_{(AB)n}+D'_{(CB)n}+6D'_{(DB)n}+2D'_{(IB)n}\left\{\frac{y_{1n}(y_{1n}-y_{2n})}{\ell_x^2}\right\}}{1+3D'_{(AB)n}-D'_{(CB)n}-3D'_{(DB)n}}\right]\ell_x \tag{49}$$

Like the above, the expressions to determine lateral force distribution in the case of accompany with a rotation are somewhat complicated. But, the distribution may be required from the repeated calculation to have been discussed in former. The numerical calculation is shown in Fig. 19. This result corresponds to what has been discussed in the former chapter.

(4.2) Stiffness and Lateral Force Distribution by means of Stress-Controlled Calculation on Arbitrary Arrangement of Aseismatic Walls in Elastic or Plastic Range.

The fundamental equation to determine lateral force distribution on aseismatic walls of the symmetric arrangement in elastic or plastic range, may be required similarly with the way of bracings. (Fig. 20) Now, when the aseismatic walls to be arranged at the n-th story in A frame have reached the shear yield stress and exist at the perfectly plastic range, the angle of deflection based on the shearing deformation is,

$${}_sR_{An}=K_{on}\cdot{}_sR_o=K_{on}\cdot 2(1+\nu)\frac{\tau_o}{E} \tag{50}$$

where, $k=1$ is assumed. In this case, the total angle of deflection at the n-th story in A, B frame, that is R_{An}, R_{Bn}, is given as below,

$$R_{An}=\left\{\frac{2(1+\nu)\tau_o}{E}\right\}K_{on}+\frac{2}{E\ell}\sum_{i=1}^{n}\sigma_{Ai}h_i \tag{51}$$

$$R_{Bn}=\frac{h_n^2}{2EA_{Bn}^2}Q_{Bn}+\frac{2}{E\ell}\sum_{i=1}^{n}\sigma_{Bi}\cdot h_i \tag{52}$$

where, $R_{An}=R_{Bn}$ and if $A_{An}=A_{Bn}=A_n$

$$\left\{2(1+\nu)\tau_o K_{on}+\frac{2}{\ell}\sum_{i=1}^{n}(\sigma_{Ai}-\sigma_{Bi})h_i\right\}A_n^2=\frac{h_n^2}{2}Q_{Bn} \tag{53}$$

Then, Eq.(53) gives the following equation to determine the distribution at the n-th story,

$$D_n=\frac{Q_{An}}{Q_{Bn}}=\frac{{}_sK_{Bn}}{{}_sK_{An}}\mu_{(AB)n}=\frac{{}_sD_{An}}{{}_sD_{Bn}}\mu_{(AB)n} \tag{54}$$

where, the correct coefficient is

$$\mu_{(AB)n}=\frac{1}{\left[K_{on}+\frac{1}{(1+\nu)\ell}\cdot\frac{\sum_{i=1}^{n}(\sigma_{Ai}-\sigma_{Bi})h_i}{\tau_o}\right]} \tag{55}$$

When the axial stress acting on the aseismatic walls at the n-th story is denoted by τ_{wn}.

$$\text{if } \tau_{wn}\leqq\tau_o(\text{in elastic range})\text{-----}\ \tau_o=\tau_{wn},\ K_{on}=1\ \Big\} \tag{56}$$

if $\tau_{wn} > \tau_0$ (in plastic range) ----- $\tau_{wn} = \tau_0, K_0 = \frac{{}_sR_{An}}{{}_sR_0} > 1$)

Also, if $h_i = h$, K_{on} is given as below,

$$K_{on} = \frac{{}_sR_{An}}{{}_sR_0} = \frac{h}{(1+\nu)l}\frac{1}{\tau_0}\left[\frac{lh}{2A_n}\left(\frac{Q_{Bn}}{2A_n}\right) - \sum_{i=1}^{n}(\sigma_{Ai} - \sigma_{Bi})\right] \quad (57)$$

Like the above, lateral force distribution on aseismatic walls in elastic or plastic range, may be required. The method of this calculation corresponds to that of bracings. The fundamental equation to determine lateral force distribution on asymmetric arrangement may be treated as Eqs.(46)~(49).

The numerical calculation is shown in Fig. 21.

(4.3) Comparison of Experimental Results of Achlilite Model and Results of Stress-Controlled Calculation.

We indicate the experimental results on stiffness and lateral force distribution with the achlilite to hold bracings, as shown in Fig. 22. When the horizontal load apply parallel to the plane direction of the arrangement shown in Fig. 23, stiffness of each type which is expressed by the horizontal displacement at the highest story, is shown in Fig. 24. The ordinate shows the number of bracings to be arranged in the each of ridge direction that has 3 spans. According to this results, the maximum horizontal displacement was shown at the continuous arrangement, and the minimum value at the uniformly dispersive arrangement. Fig. 25 (a) ~ (d) show lateral force distribution modulus λ_n on the arrangements of beam direction. In that figure, solid lines show experimental values and dotted lines are values by Stress-Controlled Calculation. According to the above, the profit of dispersive arrangements has been indicated, and the experimental results almost correspond to the values of calculation. The above does not contradict to the results with the steel model or the numerical calculation discussed in the former chapter.

(4.4) Fundamental Equations of Stress-Controlled Calculation on Reinforced Concrete Construction.

Considering the character of reinforced concrete which contains the shearing deformation of aseismatic elements and the bending deformation mechanism on the whole structure, in order to revise the equivalent axial stress of bracings and columns, we introduce newly the correct coefficient of shearing stiffness and bending stiffness. And then, Stress-Controlled Calculation is revised like the form which is possible to express the change of lateral force distribution caused by arrangements with the change of the external force.

The above result is shown as follows,

$$D_n = \frac{Q_{An}}{Q_{Bn}} = \frac{({}_sD_{An})_I}{({}_sD_{Bn})_I}\mu_{(AB)n} \quad (58)$$

$$\mu_{(AB)n}=\frac{\dfrac{{}_{s}k_{An}}{{}_{s}k_{Bn}}\cdot X_{(AB)n}}{\left[1+\left(\dfrac{\sin 2\theta_n}{2l}\right)\dfrac{\sum_{i=1}^{n}\left(\dfrac{\sigma_{A2i}}{{}_{m}k_{A2i}}-\dfrac{\sigma_{A1i}}{{}_{m}k_{A1i}}\right)h_i-\left\{\sum_{i=1}^{n}\left(\dfrac{\sigma_{B2i}}{{}_{m}k_{B2i}}-\dfrac{\sigma_{B1i}}{{}_{m}k_{B1i}}\right)h_i\right\}X_{(AB)n}}{\dfrac{\sigma_{dn}}{{}_{s}k_{An}}}\right]} \tag{59}$$

where, ${}_{s}k_{An}$=correct coefficient of shearing stiffness at the n-th story in A-frme.

${}_{s}k_{Bn}$=correct coefficient of shearing stiffness at the n-th story in B frame.

${}_{m}k_{A2i}$=correct coefficient of bending stiffness on compressive axial force of column at the i-th story in A frame.

${}_{m}k_{B2i}$=correct coefficient of bending stiffness on compressive axial force of column at the i-th story in B frame.

${}_{m}k_{A1i}$=correct coefficient of bending stiffness on tensile axial force of column at the i-th story in A frame.

${}_{m}k_{B1i}$=correct coefficient of bending stiffness on tensile axial force of column at the i-th story in B frame.

σ_{A2i}=compressive axial stress of column at the i-th story in A frame.

σ_{B2i}=compressive axial stress of column at the i-th story in B frame.

σ_{A1i}=tensile axial stress of column at the i-th story in A frame.

σ_{B1i}=tensile axial stress of column at the i-th story in B frame.

$({}_{s}D_{An})_I$=initial shearing stiffness at the n-th story in A frame.

$({}_{s}D_{Bn})_I$=initial shearing stiffness at the n-th story in B frame.

The results of calculation on the continuous and dispersive arrangements is shown in Fig. 26. We may know the character of lateral force distribution on each arrangement with the change of external force.

5. Conclusion.

In this paper, at first, the continuous arrangement to have been adopted customarily was discussed and that lateral force distribution was required newly by finite difference and the contrary effect was indicated. At next, uniformly dispersive arrangements are especially effective, was indicated. At the later, Stress-Controlled Calculation was introduced, that is what may require easily lateral force distribution on arrangements of aseismatic elements. Through the examples, lateral force distribution on the dispersive arrangements was shown.

We think that the freedom on sturctural planning increase by means of using stiffness and lateral force distribution on the arrangements of aseismatic elements.

REFERENCES

1. Tani, S. "Effectiveness of Bracing Arrangements in Imparting Stiffness Against Lateral Forces." Trans. of A.I.J. June 1958, No. 59
   Lateral Force Distribution in Continuous and Dispersive Bracings in Three Dimentional 1 Span, Many Storied Framed Structure.
2. Tani, S. "Effectiveness of Bracing Arrangements in Imparting Stiffness Against Lateral Forces." Trans. of A.I.J. Feb. 1959, No. 61
   Lateral Force Distribution in Continuous and Dispersive Elastic or Plastic Bracings in Three Dimentional Framed Structures Using the Method of Difference Equation and Stress-Controlled Calculation.
3. Tani, S. "Effectiveness of Quake Resisting Wall Arrangements in Imparting Stiffness Against Lateral Force." Bulletin of Sci. and Eng. Reseach. Lab. Waseda Univ. Oct. 1959, No. 13
   Lateral Force Distribution in Continuous and Dispersive Elastic or Plastic Quake Resisting Walls in Three Dimensional Framed Structure. Using the Method of Stress-Controlled Calculation.
4. Tani, S. "Effectiveness of Bracing Arrangements in Imparting Stiffness Against Lateral Forces." Trans. of A.I.J. June 1959, No. 62
   Lateral Force Distribution in Continuous and Dispersive Elastic or Plastic Bracings is Three Dimentional Framed Structure. Using the Method of Stress-Controlled Calculation included parallel Transformation and Rotation.
5. Tani, S. "Effectiveness of Bracing Arrangement in Imparting Stiffness Against Lateral Forces."
   Lateral Force Distribution in Continuous and Dispersive Reinforced Bracings is Framed Structure. Using the Method of Stress-Controlled Calculation.
   Trans. of A.I.J. Oct. 1959, No. 63
6. Tani, S. and Sakurai, J.
   "Experimental Studies on Effectiveness of Bracing Arrangement in Imparting Stiffness Against Lateral Forces by Plastics Model."
   Trans. of A.I.J. Oct. 1959, No. 63
7. Tani, S. and Kinoshita, K.
   "Experimental Studies on Effectiveness of Bracing Arrangement in Imparting Stiffness Against Lateral Forces by Reinforced Concrete Model."
   Trans. of A.I.J. Oct. 1959, No. 63

FIG.1

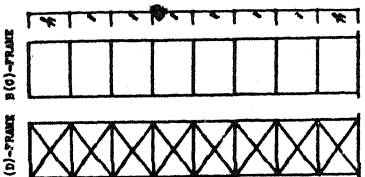


FIG.2

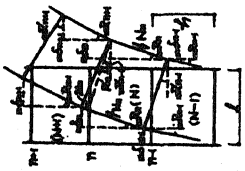


FIG.3

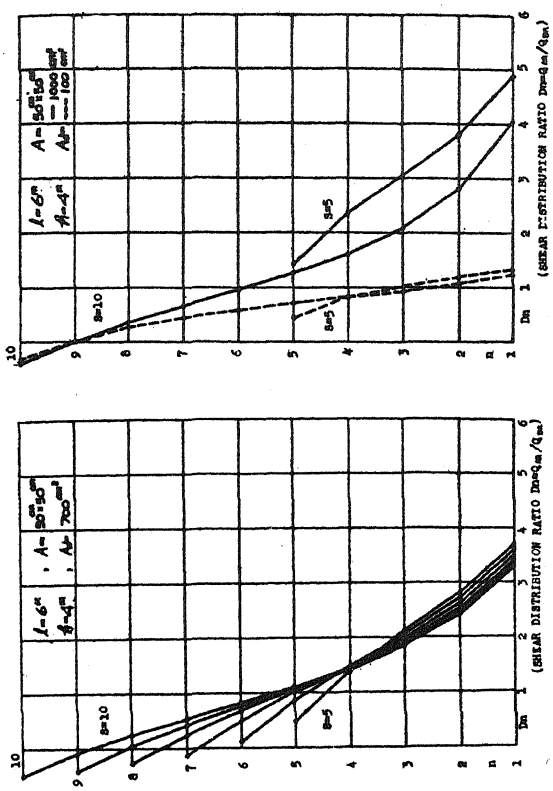


FIG.4 TENDENCY OF LATERAL FORCE DISTRIBUTION IN FRAME (SHEAR DISTRIBUTION RATIO Dn=Qm/Qm)

FIG.5.TENDENCY OF LATERAL FORCE DISTRIBUTION IN FRAME (SHEAR DISTRIBUTION RATIO Dn=Qm/Qm)

FIG.8.

FIG.9

FIG.6.RELATION BETWEEN SHEARING AND BENDING DEFORMATION

FIG.7.RELATION BETWEEN SHEARING AND BENDING DEFORMATION

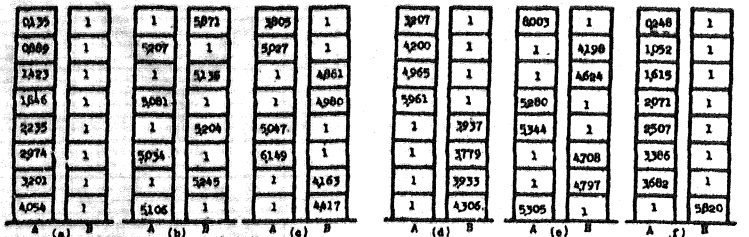


FIG.10. LATERAL FORCE DISTRIBUTION RATIO ON BRACINGS OF UNIFORM SECTION ARRANGED DISPERSIVELY

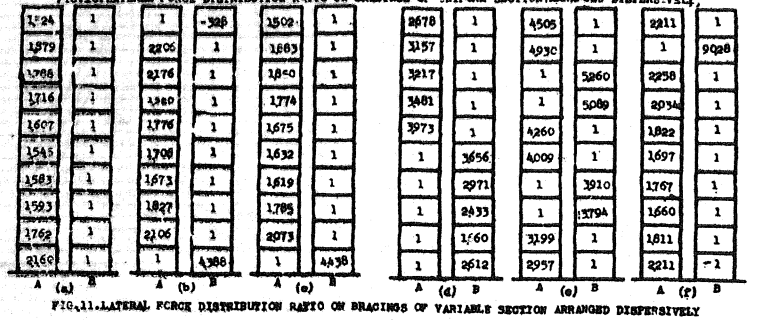


FIG.11. LATERAL FORCE DISTRIBUTION RATIO ON BRACINGS OF VARIABLE SECTION ARRANGED DISPERSIVELY

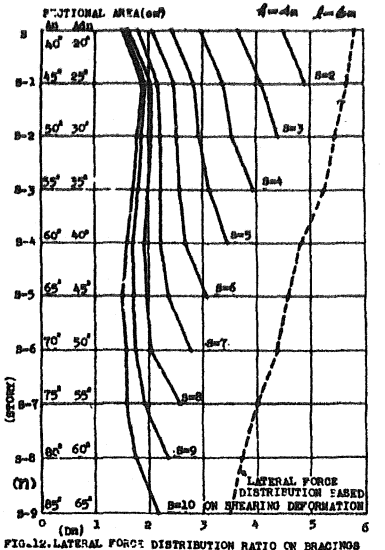


FIG.12. LATERAL FORCE DISTRIBUTION RATIO ON BRACINGS ARRANGED CONTINUOUSLY

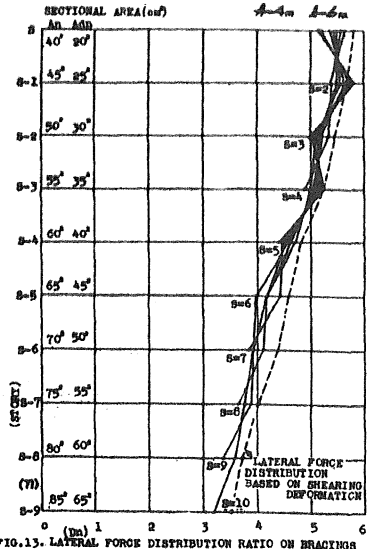
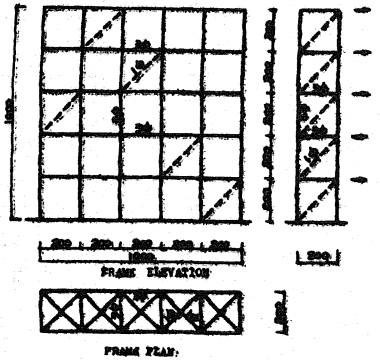


FIG.13. LATERAL FORCE DISTRIBUTION RATIO ON BRACINGS ARRANGED DISPERSIVELY



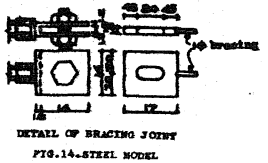


FIG.14. STEEL MODEL

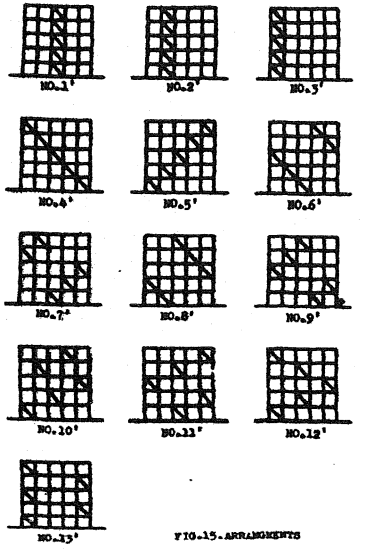


FIG.15. ARRANGEMENTS

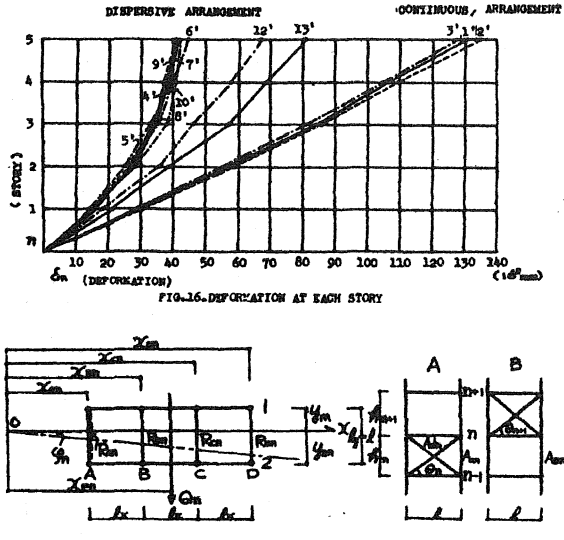
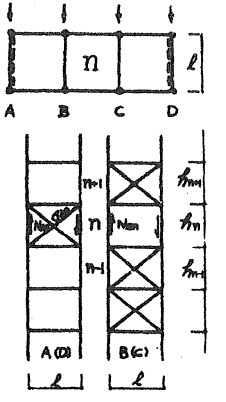


FIG.16. DEFORMATION AT EACH STORY

FIG.16. DISPLACEMENT OF ROTATION



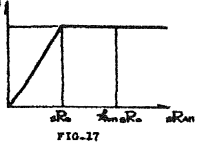
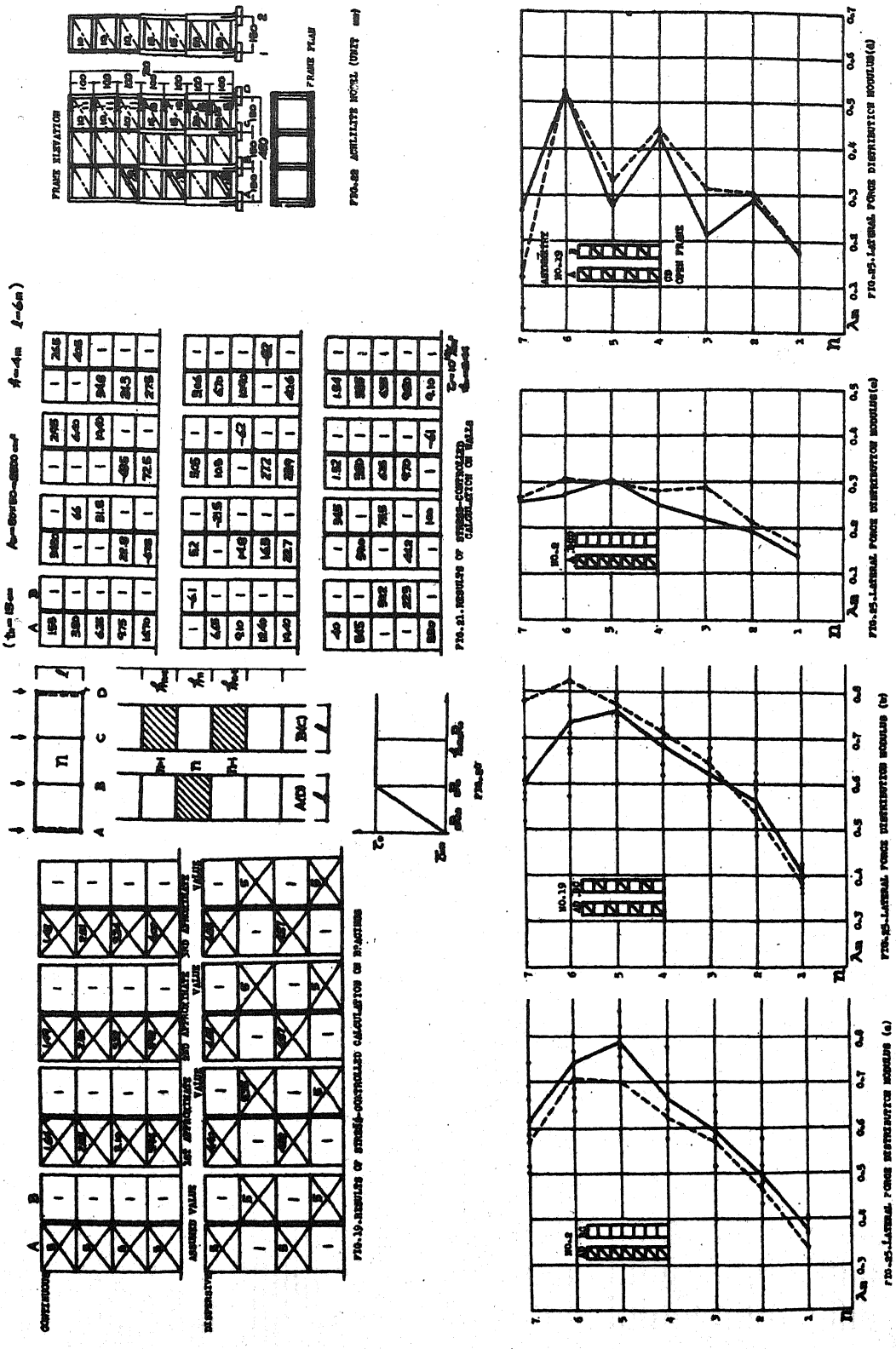


FIG.17



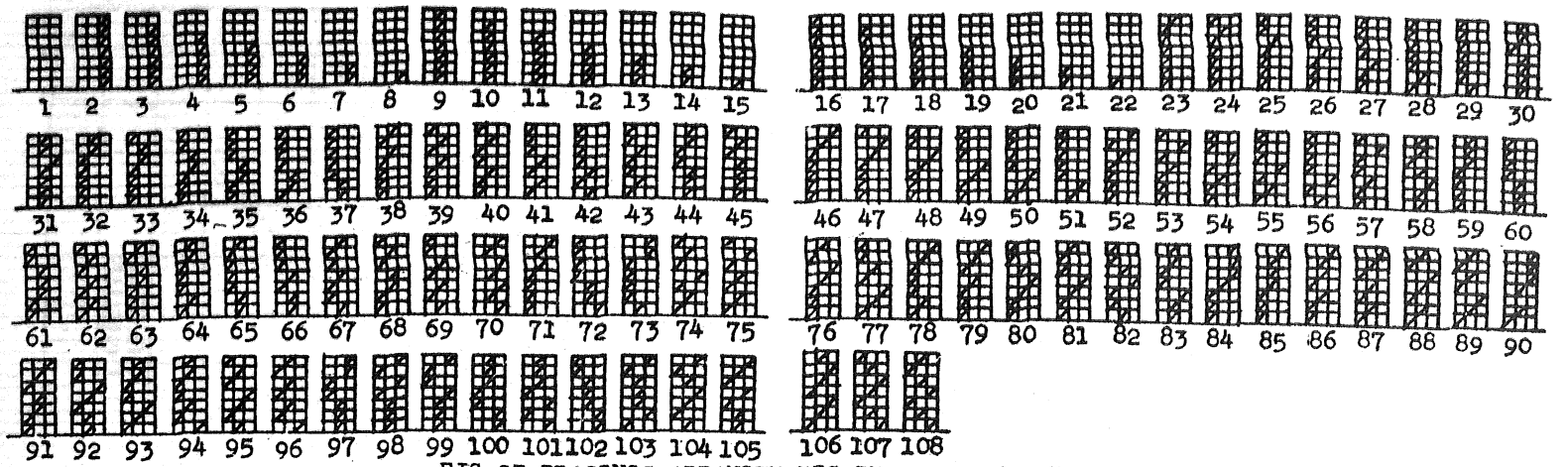


FIG.23.BRACINGS ARRANGEMENTS IN RIDGE DIRECTION

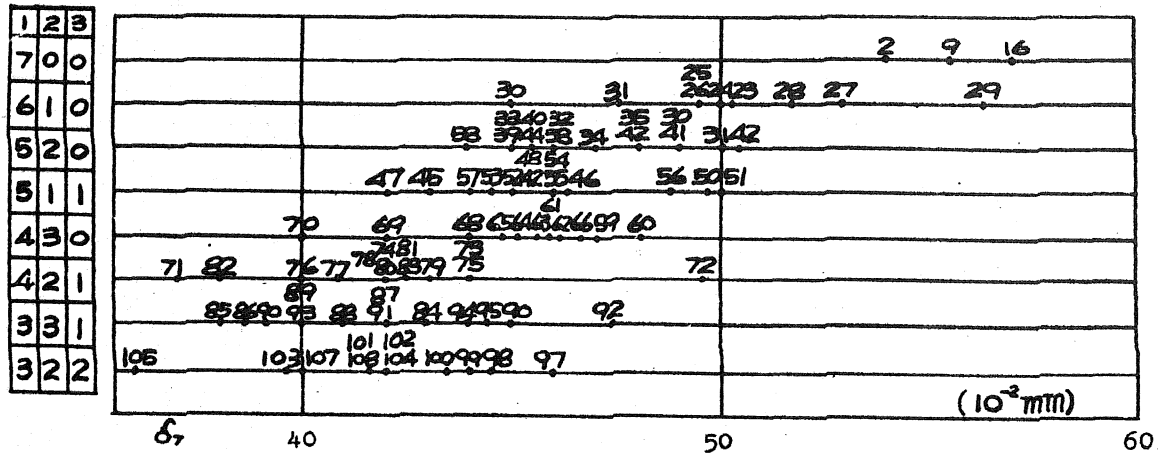


FIG.24.HORIZONTAL DISPLACEMENT AT 7-th STORY

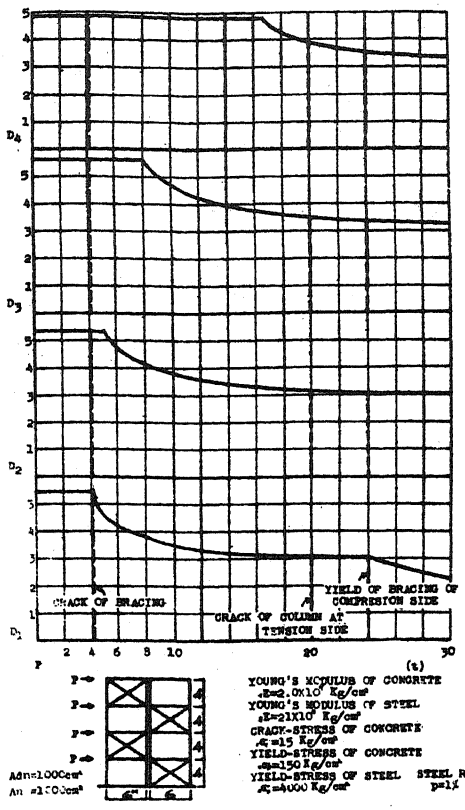


FIG.26.LATERAL FORCE DISTRIBUTION RATIO D_n ON DISPERSIVE ARRANGEMENT(b) (REINFORCED CONCRETE STRUCTURE)

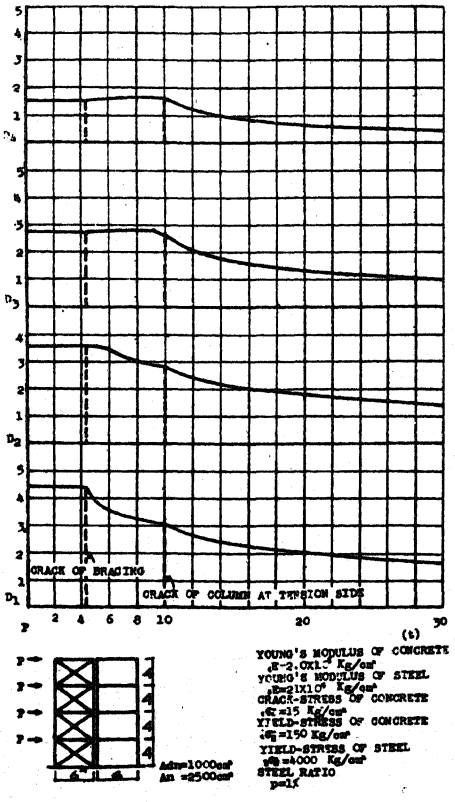


FIG.26.LATERAL FORCE DISTRIBUTION RATIO D_n ON CONTINUOUS ARRANGEMENTS (a) (REINFORCED CONCRETE STRUCTURE)