

STUDY ON ARRANGEMENTS OF ASEISMATIC ELEMENTS

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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 recommended 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 shows 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 achilite 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

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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,

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

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} .

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

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

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

$$mR_{An} - mR_{A(n-1)} = \frac{2h^2}{A_{An}E\ell^2} \sum_n Q_{An} \quad (3)$$

similarly,

$$mR_{A(n-1)} - mR_{A(n-2)} = \frac{2h^2}{A_{A(n-1)}E\ell^2} \sum_{n-1} Q_{A} \quad (4)$$

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 ,

$$mR_{A(n+1)} - 2mR_{An} + mR_{A(n-1)} = -mK_A Q_{An} \quad (5)$$

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

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

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

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,

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

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

$$sR_{An} = sK_A Q_{An} \quad (7a)$$

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

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

$$mR_{An} + sR_{An} = R_{An} \quad (9)$$

similarly, in B frame

$$mR_{Bn} + sR_{Bn} = R_{Bn} \quad (10)$$

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

$$R_{(n+1)} - 2R_n - R_{(n-1)} - sK_A Q_{A(n+1)} - (mK_A + 2sK_A) Q_{An} + sK_A Q_{A(n-1)} \quad (12)$$

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

$$sR_{Bn} = R_{Bn} = R_n = \frac{h^2}{24EI_B} Q_{Bn} \quad (13)$$

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

sK_B is denoted as follow,

$$sK_B = \frac{h^2}{24EI_B} \quad (14)$$

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

$$R_n = sK_B Q_{Bn} \quad (13a)$$

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

$$R_{(n+1)} - rR_n + R_{(n-1)} = (2A-B)(S+1)P - (2A-B)Pn \quad (15)$$

where,

$$p = \frac{2 + (mK_A + 2sK_A) \frac{1}{sK_B}}{1 + \frac{sK_A}{sK_B}} \quad (16)$$

$$A = \frac{sK_A}{1 + \frac{sK_A}{sK_B}}, \quad B = \frac{mK_A + 2sK_A}{1 + \frac{sK_A}{sK_B}}$$

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

The solution of Eq.(15) is,

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

($\because \cosh \rho = \frac{p}{2}$)

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,

$$C_1 = \frac{U_1 (\rho \cosh \rho S - \cosh(S-1)\rho) - U_2 (\cosh 2\rho - p \cosh \rho)}{(\sinh 2\rho - p \sinh \rho)(\rho \cosh \rho S - \cosh(S-1)\rho) - (\cosh 2\rho - p \cosh \rho)(\rho \sinh S\rho - \sinh(S-1)\rho)}$$

$$C_2 = \frac{-U_1 (\rho \sinh \rho S - \sinh(S-1)\rho) + U_2 (\sinh 2\rho - p \sinh \rho)}{(\sinh 2\rho - p \sinh \rho)(\rho \cosh \rho S - \cosh(S-1)\rho) - (\cosh 2\rho - p \cosh \rho)(\rho \sinh S\rho - \sinh(S-1)\rho)} \quad (19)$$

where,

$$U_1 = \left[(S-1)A - SB - \frac{2A-B}{2-p} \{ (S-1) - rS \} \right] P$$

$$U_2 = \left[B' - 2A - \frac{2A-B}{2-p} (p-2) \right] P \quad (20)$$

$$p' = \frac{1 + (mK_A + sK_A) \frac{1}{sK_B}}{1 + \frac{sK_A}{sK_B}}, \quad B' = \frac{mK_A + sK_B}{1 + \frac{sK_A}{sK_B}}$$

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,

$$D_n = \frac{Q_{An}}{Q_{Bn}} \quad (21)$$

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,

$$A'_n = A_{An} + \frac{A_{wn}}{6} \quad (22)$$

where, A_{wn} = horizontal sectional area of the aseismatic wall ($t_n \cdot l$), consequently, the bending softness coefficient ${}_m K_A$ is,

$${}_m K_A = \frac{2h^2}{AE l^2} \quad (23)$$

also, the shearing softness coefficient ${}_s K_A$ is,

$${}_s K_A = \frac{2\star(1-\nu)}{E A_{wn}} \quad (24)$$

where, ν = Poisson's ratio

\star = 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 Simultaneous 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,

$$Q_{An} + Q_{Bn} = Q_n \quad (25)$$

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

$${}_m R_{An} - {}_m R_{A(n-1)} = {}_m K_{An} \sum_n Q_{An} \quad (26)$$

where, ${}_m K_{An}$ = 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

$$mR_{Bn} - mR_{B(n-1)} = mK_{Bn} \sum_{i=1}^n Q_{Bi} \quad (27)$$

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,

$$sR_{An} = sK_{An} \cdot Q_{An} \quad (28)$$

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.

$$sR_{Bn} = sK_{Bn} \cdot Q_{Bn} \quad (29)$$

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

$$mR_{An} + sR_{An} = R_{An} \quad (30)$$

$$\text{and, } mR_{Bn} + sR_{Bn} = R_{Bn} \quad (31)$$

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

$$mR_{An} + sR_{An} = mR_{Bn} + sR_{Bn} \quad (32)$$

$mR_{A1}, mR_{A2}, \dots, mR_{An}, \dots, mR_{AS}$ can be required from Eq. (26).
 Similarly, $mR_{B1}, mR_{B2}, \dots, mR_{Bn}, \dots, mR_{BS}$ 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,

$$\begin{aligned} & \left(\sum_{i=1}^n mK_{Ai} + \sum_{i=1}^n mK_{Bi} \right) Q_{As} + \left(\sum_{i=1}^n mK_{Ai} + \sum_{i=1}^n mK_{Bi} \right) Q_{A(s-1)} + \dots \\ & + \left(\sum_{i=1}^n mK_{Ai} + \sum_{i=1}^n mK_{Bi} \right) Q_{A(n+1)} + \left\{ \left(\sum_{i=1}^n mK_{Ai} + \sum_{i=1}^n mK_{Bi} \right) + (sK_{An} + sK_{Bn}) \right\} Q_{An} \\ & + \left(\sum_{i=1}^{n-1} mK_{Ai} + \sum_{i=1}^{n-1} mK_{Bi} \right) Q_{A(n-1)} + \dots + (mK_{A1} + mK_{B1}) Q_{A1} \\ & = \left(\sum_{i=1}^n mK_{Bi} \right) Q_{Bs} + \left(\sum_{i=1}^n mK_{Bi} \right) Q_{B(s-1)} + \dots + \left(\sum_{i=1}^n mK_{Bi} \right) Q_{B(n+1)} \\ & + \left(\sum_{i=1}^n mK_{Bi} + sK_{Bn} \right) Q_{Bn} + \left(\sum_{i=1}^{n-1} mK_{Bi} \right) Q_{B(n-1)} + \dots + \left(\sum_{i=1}^n mK_{Bi} \right) Q_{B2} \\ & + (mK_{B1}) Q_{B1} \end{aligned} \quad (33)$$

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 forward. 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 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)

$$sR_{An} = K_{on} \cdot sR_0 = K_{on} \cdot \frac{2\sigma_0}{E \sin 2\theta_n} \quad (34)$$

$$\text{where, } K_{on} = \frac{sR_{An}}{sR_0} \quad (35)$$

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,

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

$$R_{Bn} = \frac{h_n^2}{2EA_{Bn}^2} Q_{Bn} + \frac{2}{El} \sum_{i=1}^n \sigma_{Bi} \cdot h_i \quad (37)$$

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

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

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

$$D_n = \frac{Q_{An}}{Q_{Bn}} = \frac{sK_{Bn}}{sK_{An}} \cdot \mu_{(AB)n} = \frac{sD_{An}}{sD_{Bn}} \mu_{(AB)n} \quad (39)$$

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,

$$\mu_{(AB)n} = \frac{1}{\left[K_{on} + \frac{\sin 2Q_n}{\ell} \cdot \frac{\sum_{i=1}^n (\sigma_{Ai} - \sigma_{Bi}) h_i}{\sigma_0} \right]} \quad (40)$$

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

$$\left. \begin{aligned} \text{if } \sigma_{dn} \leq \sigma_0 \text{ (in elastic range)} & \text{----- } \sigma_0 = \sigma_{dn}, K_{on} = 1 \\ \text{if } \sigma_{dn} > \sigma_0 \text{ (in plastic range)} & \text{----- } \sigma_{dn} = \sigma_0, K_o = \frac{sR_{An}}{sR_o} > 1 \end{aligned} \right\} \quad (41)$$

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

$$K_{on} = \frac{sR_{An}}{sR_o} = \frac{2 \sin^2 Q}{6_0} \left\{ -\frac{\ell h}{2A_n} \left(\frac{Q_{Bn}}{2A_n} \right) - \sum_{i=1}^n (\sigma_{Ai} - \sigma_{Bi}) \right\} \quad (42)$$

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,

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

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,

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

$$R_{Bn} = sK_{Bn} \cdot Q_{Bn} + \frac{2}{E\ell} \sum_{i=1}^n \sigma_{Bi} h_i \quad (45)$$

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

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

where,

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

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

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

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

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

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 Aseismic Walls in Elastic or Plastic Range.

The fundamental equation to determine lateral force distribution on aseismic walls of the symmetric arrangement in elastic or plastic range, may be required similarly with the way of bracings. (Fig. 20) Now, when the aseismic 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,

$$sR_{An} = K_{on} \cdot sR_o = K_{on} \cdot 2(1+\nu) \frac{\tau_o}{E} \quad (50)$$

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,

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

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

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

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

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

$$D_n = \frac{Q_{An}}{Q_{Bn}} = \frac{sK_{An}}{sK_{Bn}} \mu_{(AB)n} = \frac{sD_{An}}{sD_{Bn}} \mu_{(AB)n} \quad (54)$$

where, the correct coefficient is

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

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

$$\text{if } \tau_{wn} \leq \tau_o \text{ (in elastic range) } \dots \tau_o = \tau_{wn}, K_{on} = 1 \quad (56)$$

if $\tau_{wa} > \tau_o$ (in plastic range) ----- $\tau_{wa} = \tau_o, K_o = \frac{sR_{An}}{sR_o} > 1$)

Also, if $k_i = k$, K_{on} is given as below,

$$K_{on} = \frac{sR_{An}}{sR_o} = \frac{k}{(1+\nu)l} \frac{1}{\tau_o} \left[\frac{lk}{2A_n} \left(\frac{Q_{Bn}}{2A_n} \right) - \sum_{i=1}^n (\sigma_{Ai} - \sigma_{Bi}) \right] \quad (57)$$

Like the above, lateral force distribution on aseismic 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,

$$D_n = \frac{Q_{An}}{Q_{Bn}} = \frac{(sD_{An})_1}{(sD_{Bn})_1} \mu_{(AB)n} \quad (58)$$

$$\mu_{(AB)n} = \frac{\frac{s_{k_{AN}}}{s_{k_{BN}}} \cdot X_{(AB)n}}{\left[1 + \left(\frac{\sin 2\theta_n}{2L} \right) \frac{\sum_{i=1}^n \left(\frac{\sigma_{A2i}}{m k_{A2i}} - \frac{\sigma_{A1i}}{m k_{A1i}} \right) r_i - \left\{ \sum_{i=1}^n \left(\frac{\sigma_{B2i}}{m k_{B2i}} - \frac{\sigma_{B1i}}{m k_{B1i}} \right) r_i \right\} X_{(AB)n}}{\frac{\sigma_{Dn}}{s_{k_{AN}}} X_{(AB)n}} \right]} \quad (59)$$

where, $s_{k_{AN}}$ = correct coefficient of shearing stiffness at the n-th story in A-frame.

$s_{k_{BN}}$ = 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.

$(sD_{AN})_i$ = initial shearing stiffness at the n-th story in A frame.

$(sD_{BN})_i$ = 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 structural planning increase by means of using stiffness and lateral force distribution on the arrangements of aseismatic elements.

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Study on Arrangements of Aseismic Elements

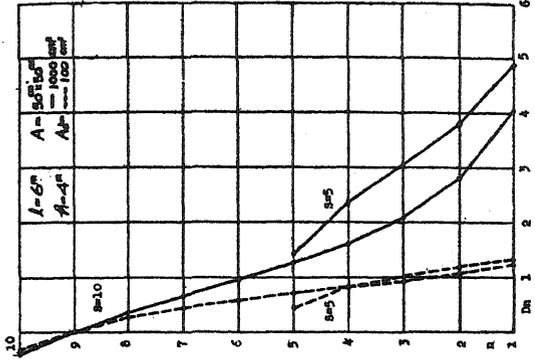


FIG. 5. TENDENCY OF LATERAL FORCE DISTRIBUTION IN FRAME (SHEAR DISTRIBUTION RATIO $Dm=Qm/Qm$)

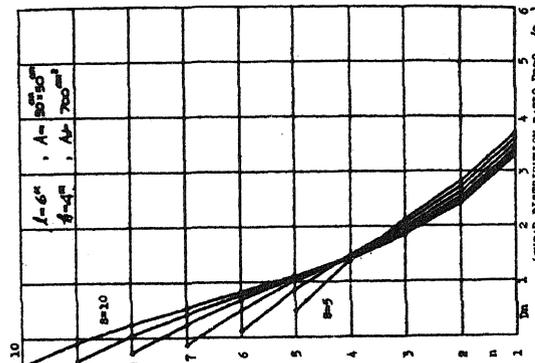


FIG. 4. TENDENCY OF LATERAL FORCE DISTRIBUTION IN FRAME (SHEAR DISTRIBUTION RATIO $Dm=Qm/Qm$)

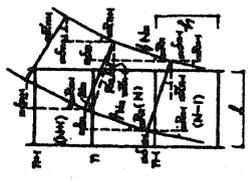


FIG. 3

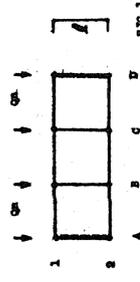


FIG. 1

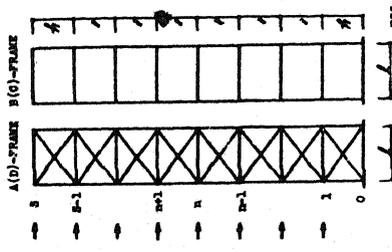


FIG. 2

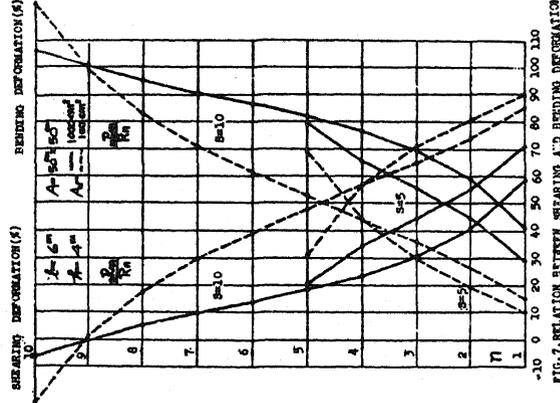


FIG. 7. RELATION BETWEEN SHEARING AND BENDING DEFORMATION

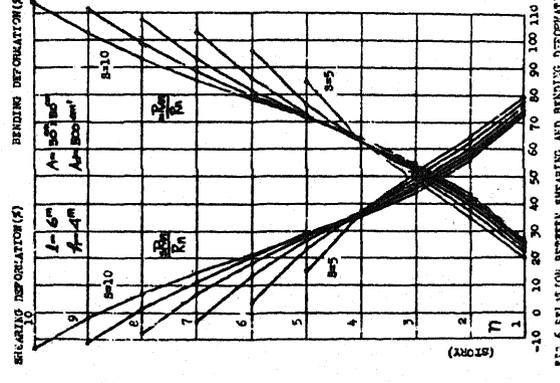


FIG. 6. RELATION BETWEEN SHEARING AND BENDING DEFORMATION

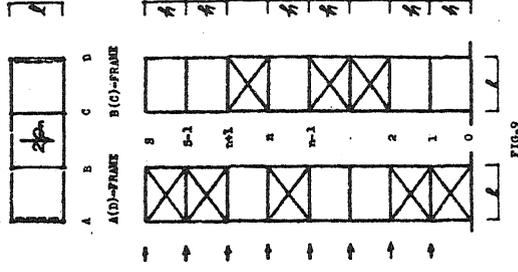


FIG. 9

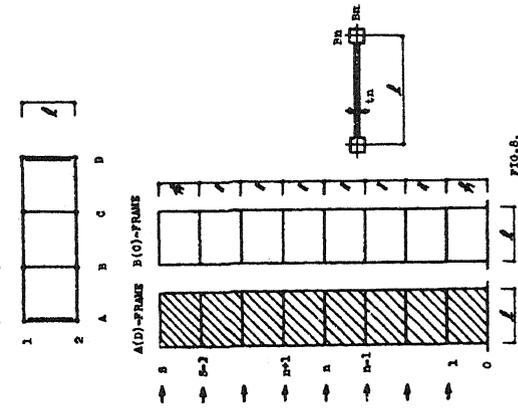


FIG. 8

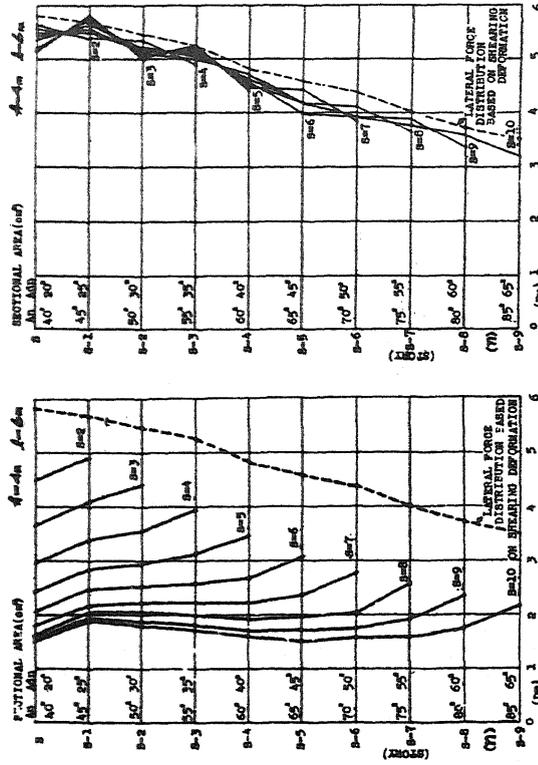


FIG. 12. LATERAL FORCE DISTRIBUTION RATIO ON BRACINGS ARRANGED CONTINUOUSLY

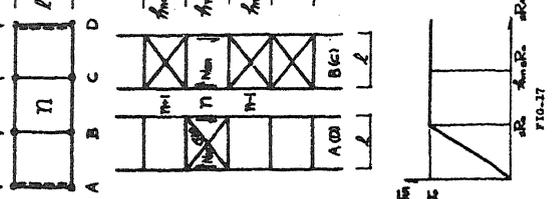
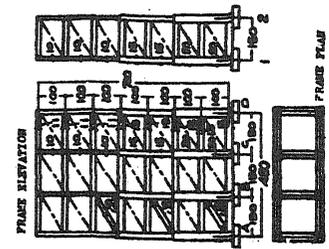
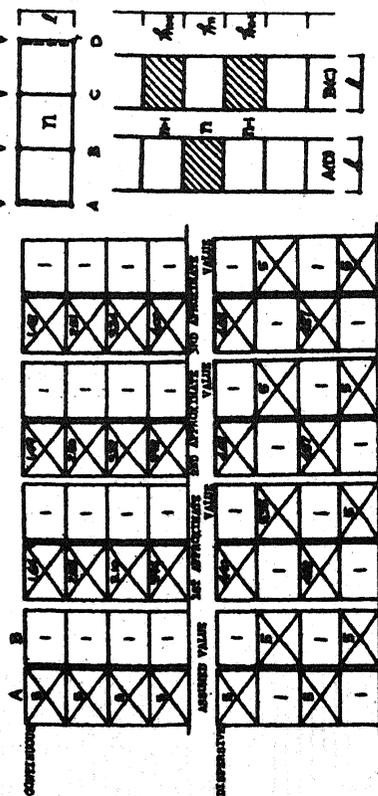


FIG. 13. LATERAL FORCE DISTRIBUTION RATIO ON BRACINGS ARRANGED DISPERSIVELY

A		B		C		D		E		F	
3075	3077	3079	3081	3083	3085	3087	3089	3091	3093	3095	3097
3099	3101	3103	3105	3107	3109	3111	3113	3115	3117	3119	3121
3123	3125	3127	3129	3131	3133	3135	3137	3139	3141	3143	3145
3147	3149	3151	3153	3155	3157	3159	3161	3163	3165	3167	3169
3171	3173	3175	3177	3179	3181	3183	3185	3187	3189	3191	3193
3195	3197	3199	3201	3203	3205	3207	3209	3211	3213	3215	3217
3219	3221	3223	3225	3227	3229	3231	3233	3235	3237	3239	3241
3243	3245	3247	3249	3251	3253	3255	3257	3259	3261	3263	3265
3267	3269	3271	3273	3275	3277	3279	3281	3283	3285	3287	3289
3291	3293	3295	3297	3299	3301	3303	3305	3307	3309	3311	3313
3315	3317	3319	3321	3323	3325	3327	3329	3331	3333	3335	3337
3339	3341	3343	3345	3347	3349	3351	3353	3355	3357	3359	3361
3363	3365	3367	3369	3371	3373	3375	3377	3379	3381	3383	3385
3387	3389	3391	3393	3395	3397	3399	3401	3403	3405	3407	3409
3411	3413	3415	3417	3419	3421	3423	3425	3427	3429	3431	3433
3435	3437	3439	3441	3443	3445	3447	3449	3451	3453	3455	3457
3459	3461	3463	3465	3467	3469	3471	3473	3475	3477	3479	3481
3483	3485	3487	3489	3491	3493	3495	3497	3499	3501	3503	3505
3507	3509	3511	3513	3515	3517	3519	3521	3523	3525	3527	3529
3531	3533	3535	3537	3539	3541	3543	3545	3547	3549	3551	3553
3555	3557	3559	3561	3563	3565	3567	3569	3571	3573	3575	3577
3579	3581	3583	3585	3587	3589	3591	3593	3595	3597	3599	3601
3603	3605	3607	3609	3611	3613	3615	3617	3619	3621	3623	3625
3627	3629	3631	3633	3635	3637	3639	3641	3643	3645	3647	3649
3651	3653	3655	3657	3659	3661	3663	3665	3667	3669	3671	3673
3675	3677	3679	3681	3683	3685	3687	3689	3691	3693	3695	3697
3699	3701	3703	3705	3707	3709	3711	3713	3715	3717	3719	3721
3723	3725	3727	3729	3731	3733	3735	3737	3739	3741	3743	3745
3747	3749	3751	3753	3755	3757	3759	3761	3763	3765	3767	3769
3771	3773	3775	3777	3779	3781	3783	3785	3787	3789	3791	3793
3795	3797	3799	3801	3803	3805	3807	3809	3811	3813	3815	3817
3819	3821	3823	3825	3827	3829	3831	3833	3835	3837	3839	3841
3843	3845	3847	3849	3851	3853	3855	3857	3859	3861	3863	3865
3867	3869	3871	3873	3875	3877	3879	3881	3883	3885	3887	3889
3891	3893	3895	3897	3899	3901	3903	3905	3907	3909	3911	3913
3915	3917	3919	3921	3923	3925	3927	3929	3931	3933	3935	3937
3939	3941	3943	3945	3947	3949	3951	3953	3955	3957	3959	3961
3963	3965	3967	3969	3971	3973	3975	3977	3979	3981	3983	3985
3987	3989	3991	3993	3995	3997	3999	4001	4003	4005	4007	4009
4011	4013	4015	4017	4019	4021	4023	4025	4027	4029	4031	4033
4035	4037	4039	4041	4043	4045	4047	4049	4051	4053	4055	4057
4059	4061	4063	4065	4067	4069	4071	4073	4075	4077	4079	4081
4083	4085	4087	4089	4091	4093	4095	4097	4099	4101	4103	4105
4107	4109	4111	4113	4115	4117	4119	4121	4123	4125	4127	4129
4131	4133	4135	4137	4139	4141	4143	4145	4147	4149	4151	4153
4155	4157	4159	4161	4163	4165	4167	4169	4171	4173	4175	4177
4179	4181	4183	4185	4187	4189	4191	4193	4195	4197	4199	4201
4203	4205	4207	4209	4211	4213	4215	4217	4219	4221	4223	4225
4227	4229	4231	4233	4235	4237	4239	4241	4243	4245	4247	4249
4251	4253	4255	4257	4259	4261	4263	4265	4267	4269	4271	4273
4275	4277	4279	4281	4283	4285	4287	4289	4291	4293	4295	4297
4299	4301	4303	4305	4307	4309	4311	4313	4315	4317	4319	4321
4323	4325	4327	4329	4331	4333	4335	4337	4339	4341	4343	4345
4347	4349	4351	4353	4355	4357	4359	4361	4363	4365	4367	4369
4371	4373	4375	4377	4379	4381	4383	4385	4387	4389	4391	4393
4395	4397	4399	4401	4403	4405	4407	4409	4411	4413	4415	4417
4419	4421	4423	4425	4427	4429	4431	4433	4435	4437	4439	4441
4443	4445	4447	4449	4451	4453	4455	4457	4459	4461	4463	4465
4467	4469	4471	4473	4475	4477	4479	4481	4483	4485	4487	4489
4491	4493	4495	4497	4499	4501	4503	4505	4507	4509	4511	4513
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4587	4589	4591	4593	4595	4597	4599	4601	4603	4605	4607	4609
4611	4613	4615	4617	4619	4621	4623	4625	4627	4629	4631	4633
4635	4637	4639	4641	4643	4645	4647	4649	4651	4653	4655	4657
4659	4661	4663	4665	4667	4669	4671	4673	4675	4677	4679	4681
4683	4685	4687	4689	4691	4693	4695	4697	4699	4701	4703	4705
4707	4709	4711	4713	4715	4717	4719	4721	4723	4725	4727	4729
4731	4733	4735	4737	4739	4741	4743	4745	4747	4749	4751	4753
4755	4757	4759	4761	4763	4765	4767	4769	4771	4773	4775	4777
4779	4781	4783	4785	4787	4789	4791	4793	4795	4797	4799	4801
4803	4805	4807	4809	4811	4813	4815	4817	4819	4821	4823	4825
4827	4829	4831	4833	4835	4837	4839	4841	4843	4845	4847	4849
4851	4853	4855	4857	4859	4861	4863	4865	4867	4869	4871	4873
4875	4877	4879	4881	4883	4885	4887	4889	4891	4893	4895	4897
4899	4901	4903	4905	4907	4909	4911	4913	4915	4917	4919	4921
4923	4925	4927	4929	4931	4933	4935	4937	4939	4941	4943	4945
4947	4949	4951	4953	4955	4957	4959	4961	4963	4965	4967	4969
4971	4973	4975	4977	4979	4981	4983	4985	4987	4989	4991	4993
4995	4997	4999	5001	5003	5005	5007	5009	5011	5013	5015	5017
5019	5021	5023	5025	5027	5029	5031	5033	5035	5037	5039	5041
5043	5045	5047	5049	5051	5053	5055	5057	5059	5061	5063	5065
5067	5069	5071	5073	5075	5077	5079	5081	5083	5085	5087	5089
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5259	5261	5263	5265	5267	5269	5271	5273	5275	5277	5279	5281
5283	5285	5287	5289	5291	5293	5295	5297	5299	5301	5303	5305
5307	5309	5311	5313	5315	531						

Study on Arrangements of Asismatic Elements

($l_0 = 18.0m$ $A_0 = 60000-80000 \text{ cm}^2$ $f = 4m$ $l = 6m$)



FRAME ELEVATOR
FRAME STAIR

15B	15C	15D	15E	15F	15G	15H	15I	15J	15K	15L	15M	15N	15O	15P	15Q	15R	15S	15T	15U	15V	15W	15X	15Y	15Z
16B	16C	16D	16E	16F	16G	16H	16I	16J	16K	16L	16M	16N	16O	16P	16Q	16R	16S	16T	16U	16V	16W	16X	16Y	16Z
17B	17C	17D	17E	17F	17G	17H	17I	17J	17K	17L	17M	17N	17O	17P	17Q	17R	17S	17T	17U	17V	17W	17X	17Y	17Z
18B	18C	18D	18E	18F	18G	18H	18I	18J	18K	18L	18M	18N	18O	18P	18Q	18R	18S	18T	18U	18V	18W	18X	18Y	18Z
19B	19C	19D	19E	19F	19G	19H	19I	19J	19K	19L	19M	19N	19O	19P	19Q	19R	19S	19T	19U	19V	19W	19X	19Y	19Z
20B	20C	20D	20E	20F	20G	20H	20I	20J	20K	20L	20M	20N	20O	20P	20Q	20R	20S	20T	20U	20V	20W	20X	20Y	20Z
21B	21C	21D	21E	21F	21G	21H	21I	21J	21K	21L	21M	21N	21O	21P	21Q	21R	21S	21T	21U	21V	21W	21X	21Y	21Z
22B	22C	22D	22E	22F	22G	22H	22I	22J	22K	22L	22M	22N	22O	22P	22Q	22R	22S	22T	22U	22V	22W	22X	22Y	22Z
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27B	27C	27D	27E	27F	27G	27H	27I	27J	27K	27L	27M	27N	27O	27P	27Q	27R	27S	27T	27U	27V	27W	27X	27Y	27Z
28B	28C	28D	28E	28F	28G	28H	28I	28J	28K	28L	28M	28N	28O	28P	28Q	28R	28S	28T	28U	28V	28W	28X	28Y	28Z
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32B	32C	32D	32E	32F	32G	32H	32I	32J	32K	32L	32M	32N	32O	32P	32Q	32R	32S	32T	32U	32V	32W	32X	32Y	32Z
33B	33C	33D	33E	33F	33G	33H	33I	33J	33K	33L	33M	33N	33O	33P	33Q	33R	33S	33T	33U	33V	33W	33X	33Y	33Z
34B	34C	34D	34E	34F	34G	34H	34I	34J	34K	34L	34M	34N	34O	34P	34Q	34R	34S	34T	34U	34V	34W	34X	34Y	34Z
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65B	65C	65D	65E																					

Study on Arrangements of Aseismic Elements

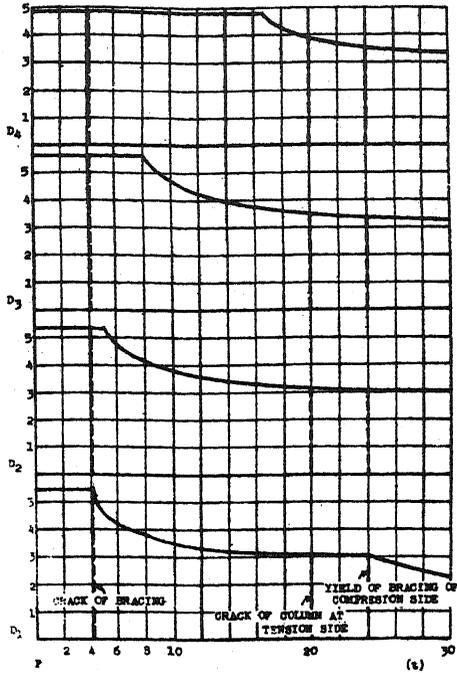


FIG. 26. LATERAL FORCE DISTRIBUTION RATIO D_n ON DISCRETE ARRANGEMENT (b) (REINFORCED CONCRETE STRUCTURE)

$E_c = 2.0 \times 10^4 \text{ Kg/cm}^2$
 $E_s = 2.1 \times 10^5 \text{ Kg/cm}^2$
 $\sigma_{ck} = 15 \text{ Kg/cm}^2$
 $\sigma_{yk} = 150 \text{ Kg/cm}^2$
 $\sigma_{sk} = 4000 \text{ Kg/cm}^2$
 $\rho = 1\%$

$A_{m1} = 100 \text{ cm}^2$
 $A_{m2} = 100 \text{ cm}^2$

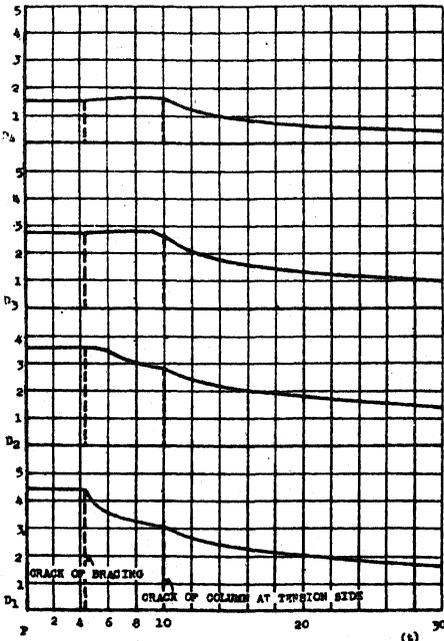


FIG. 26. LATERAL FORCE DISTRIBUTION RATIO D_n ON CONTINUOUS ARRANGEMENTS (a) (REINFORCED CONCRETE STRUCTURE)

$E_c = 2.0 \times 10^4 \text{ Kg/cm}^2$
 $E_s = 2.1 \times 10^5 \text{ Kg/cm}^2$
 $\sigma_{ck} = 15 \text{ Kg/cm}^2$
 $\sigma_{yk} = 150 \text{ Kg/cm}^2$
 $\sigma_{sk} = 4000 \text{ Kg/cm}^2$
 $\rho = 1\%$

$A_{m1} = 100 \text{ cm}^2$
 $A_{m2} = 2500 \text{ cm}^2$