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SUBJECT: Forwards responses to Structural Engineering Branch questions on masonry walls to close SER Outstanding Issue 13.Justification for use of average response spectra typical wall fix diagrams also encl.

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U.S. NUCLEAR REGULATORY COMMISSION

May 14, 1981

Mr. B. J. Youngblood, Chief
Licensing Branch No. 1
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Docket Nos. 50-387
50-388

SUSQUEHANNA STEAM ELECTRIC STATION
SER OUTSTANDING ISSUE 13
ER 100450 FILE 841-2
PLA-760

Dear Mr. Youngblood:

Attached are the responses to the Structural Engineering Branch questions on masonry walls.

These responses complete our action to close SER Outstanding Issue 13.

Very truly yours,

N W Curtis

N. W. Curtis
Vice President-Engineering & Construction-Nuclear

CTC/mks

Attachment

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SUSQUEHANNA SES UNIT 1 AND 2
DOCKET NUMBERS 50-387 AND 50-388
CATEGORY I MASONRY WALLS

PREAMBLE:

Safety related masonry walls are interior partitions whose primary function is to provide shielding and fire protection. Masonry walls are not used as primary shear walls for seismic resistance of the structure. All category I masonry walls are reinforced with all cells fully grouted. The infill material of double wythe walls is either grout or concrete. The minimum specified compressive strength for grout, concrete, and mortar is 2500 psi. Mortar infill is not used on SSES masonry walls. Metal ties, between the wythes of double wythe walls, are provided at 24" spacing maximum in horizontal and vertical directions. Seismic design is in accordance with SSES FSAR Section 3.7. Allowable stresses are as noted in FSAR Section 3.8, Table 3.8-8 and Table 3.8-9. Safety related masonry walls are Q-listed and have been added to the FSAR Design Criteria Summary (Table 3.2-1), in response to NRC, Quality Assurance Branch, Question No. 260.1-b (34).

QUESTION NO. 1:

In your response to Question 2, you indicated that Sm is the allowable stress as specified in UBC. For extreme and/or abnormal loading combinations, you increase the allowable stress by a factor of 1.67, which is in conformance with the practice of SRP Sections 3.8.3 and 3.8.4, for reinforced concrete structures. However, concrete masonry walls are quite different from reinforced concrete walls, particularly the unreinforced ones, the use of such a practice may not result in an adequate design. Depending on the types of stress, that is, tensile, shearing or axial compressive, the factor may vary from 0 to 2.5 (see enclosure 2). Specify the masonry design strength f'_m used in Susquehanna masonry walls and the allowable values for all types of stresses.

RESPONSE:

Code allowable stresses for masonry tension, shear, compression, and bond are increased by a factor of 1.67 for load combinations involving abnormal and/or extreme environmental conditions which are credible but highly improbable. Since code allowable stresses are generally associated with a factor of safety of 3, the 1.67 increase provides a factor of safety against failure of 1.8 ($3 \div 1.67$) (see Table 4 for the increase allowed for each type of stress). There are no unreinforced masonry walls on SSES project. Susquehanna SES masonry walls are designed based on an ultimate compressive strength, f'_m, of 1500 psi as specified in UBC 1976, for solid grouted hollow masonry. Minimum compressive strength at 28 days for mortar, grout, and concrete is 2500 psi. Materials are in accordance with FSAR Appendix 3.8C. The allowable stresses are as listed in Table 1.

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TABLE 1.

SSES ALLOWABLE STRESSES

Materials and Stress Type	Allowable Stress: UBC - 1976 (1) psi
1. Masonry:	$f'_m = 1500$ (see note 2)
Compression:	
Flexural	$.33f'_m = 500$
Axial	$.20f'_m \times (1-(h/40t)^3)$ h = clear height, in. t = wall thickness, in.
Flexural Shear	$1.1 \sqrt{f'_m} = 43$
Bond (deformed bars)	140
Bearing	$.25f'_m = 375$
Bed Joint tension	
Normal	(See note 3)
Parallel	25
Modulus of elasticity, E_m	$1000f'_m = 1,500,000$
Modulus of rigidity, E_v	$400f'_m = 600,000$
2. Reinforcement:	
Tension:	
Grade 40 Steel	20,000 (used for ties only)
Grade 60 Steel	24,000
Compression:	
Grade 40 Steel	16,000 (used for ties only)
Grade 60 Steel	24,000

Notes: (1) For stress increase allowed for abnormal, or extreme environmental load combinations - See Table 4.

(2) Ultimate compressive strength as specified in UBC - 1976 for solid grouted hollow concrete units - Grade N.

(3) Zero tension normal to bed joint is used.

QUESTION NO. 2

In the note to your response to Question 2, you stated that the allowable shear or tension between masonry block and concrete or grout infill is considered to be equal to three percent of the compressive strength of the block. The allowable shear or tension as specified by you is in the staff's opinion too high. To specify the allowable shear or tension of the vertical joint between wythes in terms of the compression strength of the block is in the first place unconservative and the use of seemingly low percentage of 3% may actually result in an allowable shearing stress greater than its corresponding strength. Therefore, a revision of the stress criterion is required.

RESPONSE:

The specified shear and tension, for the interface of masonry block and concrete or grout infill, of three percent of compressive strength, f'_m, is based on the relationship $1.1\sqrt{f'_m}$ given in ACI-531-79. For $f'_m = 1500$ psi, this relationship yields a value of 43 psi compared to 45 psi (.03 x 1500) allowed for evaluation of project masonry walls. The difference of 2 psi is justified by the fact that the ultimate compressive strength of masonry f'_m, is generally higher than 1500 psi.

The values for shear and tension as specified above have been used only as a guide in evaluating double wythe walls, where infill thickness is greater than 8 inches (24" thick walls and larger). For walls having an infill thickness of less than 8 inches (total of four walls), zero tension/shear is assumed for evaluation purposes.

For SSES masonry walls, the actual shear stress, as determined by VQ/Ib for uncracked sections, and in the compression zone of cracked sections ranges from 5-10 psi; except for three walls. For these three walls shearing stress is in the range of 10-15 psi.

QUESTION NO. 3

In your response to Question 4: (1) It is indicated that response spectrum method is used for the dynamic analysis of the concrete masonry walls. However, there is no mention as to which of the response spectra is used, upper floor or lower floor response spectrum or the average of the two. It is required that an upper bound envelope of the individual floor is used. (2) Though the use of ACI 318 formula the cracking of concrete masonry wall is considered. The use of such a formula is questionable in view of the fact that in a concrete masonry wall the weakest section is the bed joint and the modulus of rupture is equal to that of neither the concrete block nor the mortar. Indicate how the modulus of rupture is established in your computation.

RESPONSE ITEM (1):

Response spectrum for the lower floor has been used for evaluation of cracked/uncracked behavior of masonry walls, as applicable, for vertical motion, and for walls cantilevered from the floor. For horizontal motion, the lower floor response spectrum has been used in the initial evaluation of cracked/uncracked behavior, as applicable, for walls spanning between two floors and walls having side connection at concrete walls. These walls have also been re-evaluated based on the average acceleration of the upper and lower floors. Where the upper floor acceleration is less than the lower floor acceleration, the lower floor acceleration is used. For justification of using average acceleration, see Enclosure 1.

RESPONSE ITEM (2):

Although ACI-318 formula is derived for cracked concrete sections, the use of the formula for masonry walls takes into consideration the difference in material strengths. The difference between masonry behavior and concrete behavior is recognized and allowances are provided in selection of seismic acceleration within a frequency variation of plus or minus fifteen percent of the natural frequency.

The modulus of rupture (f_r) for masonry is approximated by increasing the UBC allowable flexural tensile stress by a factor of safety of 3 and then applying a 33% reduction to arrive at a lower bound value. This value is used only for stiffness and frequency calculations of the cracked section and not for strength. Allowance for uncertainties in the modulus of rupture is accounted for in the frequency variation of $\pm$ 15% of the natural frequency.

QUESTION NO. 4:

In response to Question 5, it is stated that when the design stresses of masonry walls exceed the allowable stresses, fixes are designed such that the criteria is satisfied. Indicate the number of walls where such fixes are needed and provide examples.

RESPONSE:

The number of masonry walls requiring fixes for cracked section criteria is 36. Wall location, thickness, and elevation are as shown in Table 2. Typical fixes are shown in details type 1, type 2, type 3, and type 4 (see Enclosure 2).

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TABLE 2

SSES - MASONRY WALLS
WALLS WHICH REQUIRED FIXES FOR CRACKED SECTION CRITERIA

BLDG.	FLOOR ELEVATION	WALL THICKNESS	NO. OF WALLS	REF. DWG.
Control	656'-0	8"	2	C-1301
Control	741'-0	6"	2	C-1304
Control	741'-0	8"	3	C-1304
Control	753'-0	8"	1	C-1304
Control	771'-0	8"	16	C-1304
Control	783'-0	1'-0"	3	C-1307
Control	806'-0	8"	3	C-1308
Control	806'-0	1'-0"	1	C-1308
Reactor	728'-0	8"	1	C-1202
Reactor	799'-0	8"	4	C-1205

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QUESTION NO. 5:

Provide justification for any deviation from the attached staff's interim criteria in your design and analysis of the masonry walls.

RESPONSE:

Deviations and justification for differences between SSES criteria and SEB interim criteria are as noted in the following paragraphs.

Items which are not specifically addressed are in accordance with the criteria or not applicable to the project.

ITEM NO. 1: General Requirments

The materials, testing, analysis, design, construction and inspection related to the design and construction of safety-related concrete masonry walls shall conform to the applicable requirements contained in Uniform Building Code - 1979, unless specified otherwise, by the provisions in this criteria.

RESPONSE:

Uniform Building Code, 1976 edition, has been used for design and evaluation of Susquehanna masonry walls. A comparison of 1976 and 1979 editions of UBC shows no significant difference in criteria applicable to SSES masonry walls. In addition, ACI-531-79 is used to supplement UBC allowable stresses, and ACI-318 1977 in stiffness calculations:

ITEM NO. 2: Loads and Load Combinations

The loads and load combinations shall include consideration of normal loads, severe environmental load, extreme environmental load, and abnormal loads. Specifically, for operating plants, the load combinations provided in plant's FSAR shall govern. For operating license applications, the following load combinations shall apply for definition of load terms, (see SRP Section 3.8.4.11-3).

RESPONSE:

For comparison of SEB interim load combinations and load combinations used for masonry walls evaluation see Table 3. Definition of terms is as shown below.

Notation

D = Dead load of structure plus any other permanent loads contributing stress.

L = Live loads expected to be present when the plant is operating, including movable equipment, piping, cables.

P = Design basis accident pressure loads.

R = Steam/water jet forces or reactions resulting from rupture of process piping.

T_o = Thermal effects during normal operating conditions including temperature gradient and equipment and pipe reactions.

H_o = Force on structure due to thermal expansion of pipes under operating conditions.

T_a = Added thermal effects (over and above operating thermal effects) which occur during a design accident.

H_a = Force on structure due to thermal expansion of pipes under accident conditions.

E = Load due to Operating Basis Earthquake.

E' = Load due to Design Basis Earthquake.

W = Wind load.

W' = Tornado wind load.

D_s = Force on blockwall due to story drift under Operating Basis Earthquake Loading.

D'_s = Force on blockwall due to story drift under Safe Shutdown Earthquake Loading.

TABLE 3. - LOAD COMBINATION COMPARISON

LOAD COMBINATION	SEB INTERIM CRITERIA	SSES FSAR CRITERIA	COMMENTS
Service Load Condition	1. $D + L$	1. $D + L$	
	2. $D + L + E$	2. $D + L + E + D_s$	
	3. $D + L + W$	3. Not Applicable	No wind pressure
	1a. $D + L + T_o + R_o$	1a. $D + L + T_o + H_o$	
	2a. $D + L + T_o + R_o + E$	2a. $D + L + T_o + H_o + E$	
	3a. $D + L + T_o + R_o + W$	3a. Not Applicable	No wind pressure
Extreme environmental	4. $D + L + T_o + R_o + E'$	4. $D + L + T_o + H_o + E' + D'_s$	
	5. $D + L + T_o + R_o + W_t$	5. $D + L + T_o + H_o + W'$	See note 2
abnormal	6. $D + L + T_a + R_a + 1.5\ P_a$	6. $D + L + (T_o + T_a) + R + 1.25\ P_a + H_a$	See note 1
abnormal/severe environmental	7. $D + L + T_a + 1.25\ P_a + 1.0\ (Y_r + Y_j + Y_m) + 1.25E + R_a$	7. $D + L + (T_o + T_a) + 1.25\ P_a + R + 1.25\ E + D_s$	
abnormal/ extreme environmental conditions	8. $D + L + T_a + R_a + 1.0\ P + 1.0\ (Y_r + Y_j + Y_m) + 1.0E'$	8. $D + L + (T_o + T_a) + R + 1.0\ P + 1.0\ E' + D'_s$	

Notes: (1) Abnormal load combination in SSES-FSAR Table 3.8-9. Part C will be revised to read $D + L + (T_o + T_a) + R + 1.5\ P_a + H_o$. All other load combinations will remain unchanged.

(2) W' does not include W_m, tornado missile. Masonry walls are not used for protection of safety related equipment against tornado missiles.

ITEM NO. 3: Allowable Stresses

Allowable stresses provided in chapter 24 of UBC-79, as supplemented by the following modifications/exceptions shall apply.

(a) When wind or seismic loads (OBE) are considered in the loading combinations, no increase in the allowable stresses are permitted.

RESPONSE:

Design and evaluation of masonry walls is based on a 33% increase in the allowable stress. This increase is permissible per UBC, 1979 and per ACI-531-79. The factor is also compatible with the 25% increase in stress noted in SSES FSAR for Working Stress Design Method.

ITEM NO. 3: (b) Use of allowable stresses corresponding to special inspection category shall be substantiated by demonstration of compliance with the inspection requirements of the NRC criteria.

RESPONSE:

Stresses corresponding to special inspection have been used in the design and evaluation of SSES masonry walls. Inspection required to assure that masonry construction is in accordance with Appendix "D" and amendments to the PSAR, and to assure that materials are in accordance with FSAR Appendix 3.8C is implemented. Documentation of this inspection is in project jobsite files.

ITEM NO. 3: (c) For load conditions, which represent extreme environmental, abnormal, abnormal/severe environmental, and abnormal/extreme environmental conditions the allowable working stresses may be multiplied by the factors shown in the following table: (See table 4).

TABLE 4.

STRESS INCREASE FACTOR COMPARISON

	SEB	SSES	
	FACTOR	FACTOR	JUSTIFICATION/COMMENT
Axial or flexural compression	2.5	1.67	See Response Question #1
Bearing	2.5	1.67	"
Reinforcement stress except shear	2.0	1.67	See note 1
Shear Reinforcement and/or bolts	1.5	1.5	Anchor bolts are not used in safety related masonry walls
Masonry tension Parallel to bed joint	1.5	1.5	
Shear carried by masonry	1.0	1.67	See note 2
Masonry tension perpendicular to bed joint			
For reinforced masonry	0	0	
For unreinforced masonry	1.0	N/A	No unreinforced masonry walls

(1) Shall not exceed .90 fy
(2) The actual shear stress carried by masonry is within the allowable shear stress given in UBC Table 24-H with no increase factor applied.

RESPONSE:

See table above.

QUESTION NO. 5: Design and Analysis Considerations

ITEM 4g:

In new construction, no unreinforced masonry wall is permitted, also all grout in concrete masonry walls shall be compacted by vibration.

RESPONSE:

a. There are no unreinforced masonry walls in SSES project.

b. Cell grout and/or infill grout or concrete is compacted by either mechanical vibrators or by rodding.

ITEM 4i:

Special constructions (e.g., multiwythe, composite) or other items not covered by the code shall be reviewed on a case by case basis for their acceptance.

RESPONSE:

Double wythe walls are designed as composite sections, except as noted in response to Question No. 2. Allowable stresses are per ACI-531-79.

ITEM 4j:

Licensees or applicants shall submit QA/QC information, if available, for staff's review.

RESPONSE:

Applicable QA/QC information is available at SSES jobsite and will be submitted upon request.

ENCLOSURE 1.

JUSTIFICATION FOR THE USE OF

AVERAGE RESPONSE SPECTRA
(13 PAGES)

JUSTIFICATION OF USING APPROXIMATION METHOD TO DETERMINE MAXIMUM WALL PANEL RESPONSES TO SEISMIC MOTION

The evaluations herein demonstrate that: (1) The use of the average floor acceleration response spectra to calculate the response of the wall panel is appropriate, and (2) The use of uniform inertia load with magnitude equal to the average spectral acceleration for the fundamental mode, in calculating the maximum seismic responses is a good approximation, even considering the higher mode effect.

For the purposes of this evaluation, the seismic response of a simply-supported, uniform beam simulating a strip of the wall panel with unit width is considered, as shown in Figure 1.

(1) Use of Average Spectra

The equation of motion of an undamped, simply-supported beam can be written in terms of the total displacement with respect to some fixed reference axis as:

$$m \frac{\partial^2 u}{\partial t^2} + EI \frac{\partial^4 u}{\partial x^4} = 0 \qquad (1)$$

Where $\bar{m}$ and EI are the mass density and flexural rigidity of the beam. Denote the seismic excitations at the ends of the

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the beam as U_a and U_b. Then the total displacement u(x,t) can be expressed in terms of the two seismic motions and the relative displacement to the seismic motions as:

$$u(x,t) = (x/L) \; U_b + (1 - x/L) \; U_a + r(x,t) \qquad (2)$$

Where L is the length of the beam. The relation expressed by the above equation is shown in Figure 2. The relative displacement r(x,t) needs to satisfy the following simply-supported conditions:

$$r(o,t) = r(L,t) = 0 \qquad (3)$$

$$\left.\frac{\partial^2 r}{\partial x^2}\right|_{x=o} = \left.\frac{\partial^2 r}{\partial x^2}\right|_{x=L} = 0 \qquad (4)$$

Substitute Equation 2 into Equation 1, the equation of motion in terms of relative displacement r(x,t) can be expressed as:

$$m\frac{\partial^2 r}{\partial t^2} + EI\frac{\partial^4 r}{\partial x^4} = - m(x/L) \ddot{U}_b - m(1 - x/L)\ddot{U}_a \qquad (5)$$

The eigen-function solutions for the homogeneous equation associated with Equation 5 that satisfy the boundary conditions specified by Equations 3 and 4 are:

$$\sin \frac{n\pi x}{L}, \quad n = 1, 2, 3, \ldots ,$$

and the corresponding frequencies of vibration are:

$$\omega_n = n^2 \pi^2 \sqrt{\frac{EI}{mL^4}} \qquad n = 1, 2, 3, \ldots \tag{6}$$

So, the solution of Equation 5 can be expressed as:

$$r(x,t) = \sum_{n=1}^{\infty} a_n(t) \sin \frac{n\pi x}{L} \tag{7}$$

Substitute Equation 7 into Equation 5, and multiply the latter by $\sin \frac{n\pi x}{L}$, and then integrate it with respect to x over the full length of the beam, the equation of motion can be transformed into modal equations of motion as:

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$$\ddot{a}_n + \omega^2{}_n a_n = \Gamma_n\left(\frac{\ddot{U}_a + \ddot{U}_b}{2}\right) \qquad n = 1,\ 3,\ 5,\ \cdots \tag{8a}$$

and

$$\ddot{a}_n + \omega^2{}_n a_n = \Gamma_n\left(\frac{\ddot{U}_a - \ddot{U}_b}{2}\right) \qquad n = 2,\ 4,\ 6,\ \cdots \tag{8b}$$

where Γ_n = participation factor

$$= \frac{4}{n\pi} \tag{9}$$

If damping in the form of modal damping ratio is included, Equations 8a and 8b becomes:

$$\ddot{a}_n + 2\xi_n\omega_n\dot{a}_n + \omega^2{}_n a_n = \Gamma_n\left(\frac{\ddot{U}_a + \ddot{U}_b}{2}\right) \quad n = 1,3,5,\ldots \tag{10a}$$

and

$$\ddot{a}_n + 2\xi_n\omega_n\dot{a}_n + \omega^2{}_n a_n = \Gamma_n\left(\frac{\ddot{U}_a - \ddot{U}_b}{2}\right) \quad n = 2,4,6,\ldots \tag{10b}$$

Where ξ_n is the damping ratio of the n^{th} mode.

Equation 10a means that the odd-number modes which are symmetrical about the mid-span of the beam will be excited by the average of the two seismic excitations; while equation 10b means that the even-number modes which are antisymmetrical about the mid-span of the beam will be excited by half of the difference between the two seismic excitations.

Expressing the maximum modal displacement response in equations 10a and 10b in terms of absolute acceleration response spectra gives:

$$|a_n|_{max} \leq |\Gamma_n| \left[\frac{S_a(\xi_n, \omega_n)}{2\omega_n^2} + \frac{S_b(\xi_n, \omega_n)}{2\omega_n^2} \right]$$

$$< \frac{4mL^4}{n^5 \pi^5 EI} \left[\frac{S_a(\xi_n, \omega_n) + S_b(\xi_n, \omega_n)}{2} \right] \qquad (11)$$

$$n = 1, 2, 3, \ldots$$

This illustrates that the use of the average of two floor acceleration response spectra to calculate the modal response of a wall panel is appropriate.

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(2) Contribution of Higher Modes

From Equation 11, the relative importance of modes can be evaluated by examining the frequency ratios, modal participation ratios, and maximum modal response ratios for constant acceleration which can be shown as:

$$\omega_1 : \omega_2 : \omega_3 : \ldots = 1 : 4 : 9 : \ldots : \qquad (12)$$

$$\Gamma_1 : \Gamma_2 : \Gamma_3 : \ldots = 1 : -1/2 : 1/3 : \ldots \qquad (13)$$

$$\frac{\Gamma_1}{\omega^2_1} : \frac{\Gamma_2}{\omega^2_2} : \frac{\Gamma_3}{\omega^2_3} : \ldots = 1 : -\frac{1}{32} : \frac{1}{243} : \ldots \qquad (14)$$

For an SRSS method of combining maximum response, the contribution of higher modes is clearly negligible.

If for example, the fundamental frequency ω_1 is above 8 H_z, the second frequency is above 32 H_z which is already in the rigid range, i.e., in the range of no amplification. Thus the S_a and S_b values associated with modes other than the fundamental will be the Zero-Period-Acceleration (ZPA) values of the two seismic motions U_a and U_b. Using the absolute sum (ABS) method of combining the modal maximum responses, in this case, the contribution of higher modes is not more than 4% of the fundamental mode.

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The relative importance of modes can also be evaluated by examining the moment and shear responses in the beam for each mode, as shown in the following.

The moment in the beam due to the n^{th} mode can be evaluated by:

$$M_n(X) = EI\frac{\partial^2}{\partial X^2}\left[a_n \sin\left(\frac{n\pi X}{L}\right)\right]$$

$$< \frac{4mL^2}{n^3\pi^3}\left[\frac{S_a(\xi_n,\omega_n) + S_b(\xi_n,\omega_n)}{2}\right]\sin\left(\frac{n\pi X}{L}\right) \qquad (15)$$

$$n = 1,2,3,\ldots$$

The moment at the mid-span of the beam is contributed only by the symetrical modes and can be expressed as follows:

$$M_n\left(\frac{L}{2}\right) < \frac{4mL^2}{n^3\pi^3}\left[\frac{S_a(\xi_n,\omega_n) + S_b(\xi_n,\omega_n)}{2}\right] \qquad (16)$$

$$n = 1,3,5,\ldots$$

For a constant spectral acceleration, the contibution to the mid-span moment of the beam from each mode can be expressed in the following ratio:

$$M_1\left(\frac{L}{2}\right) : M_3\left(\frac{L}{2}\right) : M_5\left(\frac{L}{2}\right) : \ldots = 1 : \frac{1}{27} : \frac{1}{125} : \ldots \qquad (17)$$

Using the SRSS Method of combining modal responses, the contribution of the higher modes to the mid-span moment is less than 1% of that from the fundamental modes. Using the ABS method of combining modal responses, the contribution of higher modes is less than about 5%.

The shear force in the beam due to the n^{th} mode can be evaluated as:

$$Q_n(X) = EI \frac{\partial^3}{\partial X^3} \left[a_n \sin\left(\frac{n\pi X}{L}\right)\right]$$

$$< \frac{4mL}{n^2\pi^2} \left[\frac{S_a(\xi_n,\omega_n) + S_b(\xi_n,\omega_n)}{2} \right] \cos\left(\frac{n\pi X}{L}\right) \qquad (18)$$

$$n = 1,2,3,4,\ldots$$

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The maximum shear occurs at the support of the beam and can be expressed as:

$$Q_n(0) < \frac{4mL}{n^2\pi^2} \left[\frac{S_a(\xi_n,\omega_n) + S_b(\xi_n,\omega_n)}{2} \right] \quad (19)$$

$$n = 1,2,3,4,\ldots$$

The contribution of the higher modes to the maximum shear at the beam support relative to that of the fundamental mode can be evaluated by comparing the modal effective masses (MEM) associated with the fundamental mode and the higher modes. The modal effective mass of the fundamental mode is

$$MEM_1 = \frac{8mL}{\pi^2} = 0.81\ mL \quad (20a)$$

The modal effective mass associated with modes higher than the fundamental mode can be calculated as

$$MEM_1' = (1 - 0.81)mL = 0.19\ mL \quad (20b)$$

The ratio of MEM_1' TO MEM_1 is 0.19/0.81 = 23%. That is the contribution of higher modes to the maximum shear is at most 23% of the contribution due to the fundamental mode. This ratio does not take into account the ratio of the spectral

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acceleration for the fundamental mode to the ZPA value for the higher modes. When the difference in spectral accelerations is accounted for, the contribution of higher modes to the maximum shear would be less than 23%. For example, if the spectral acceleration for the fundamental mode is 1.5 ZPA, then the ratio of higher mode contribution would be 0.19/(0.81 x 1.5) = 16%.

(3) Uniform Inertia Load Approximation

Using the modal responses, the maximum moment and shear of the beam can be calculated. This moment and shear can then be compared to the moment and shear based on a uniform inertia load using the average of the two floor spectral accelerations at the fundamental mode of the beam.

The maximum moment occured at the mid-span of the beam induced by a uniform load with the following magnitude:

$$f(X) = m\left[\frac{S_a\ (\xi_1,\omega_1) + S_b\ (\xi_1,\omega_1)}{2}\right] \qquad (21)$$

can be expressed as:

$$M^*\left(\frac{L}{2}\right) = \frac{mL^2}{8}\left[\frac{S_a\ (\xi_1,\omega_1) + S_b\ (\xi_1,\omega_1)}{2}\right] \qquad (22)$$

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From Equation 16, the moment at the mid-span of the beam due to the fundamental mode is:

$$M_1\left(\frac{L}{2}\right) < \frac{4mL^2}{\pi^3} \left[\frac{S_a\ (\xi_1,\omega_1) + S_b\ (\xi_1,\omega_1)}{2}\right] \qquad (23)$$

The maximum difference between the moments from Equations 22 and 23 is about 3%.

The maximum shear occurred at the support of the beam induced by the uniform load expressed in Equation 21, can be written as:

$$Q^*(0) = \frac{mL}{2} \left[\frac{S_a\ (\xi_1,\omega_1) + S_b\ (\xi_1,\omega_1)}{2}\right] \qquad (24)$$

From Equation 19, the shear at the support of the beam due to the fundamental mode is:

$$Q_1(0) < \frac{4mL}{\pi^2} \left[\frac{S_a\ (\xi_1,\omega_1) + S_b\ (\xi_1,\omega_1)}{2}\right] \qquad (25)$$

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The shear from Equation 24 is greater than the shear from Equation 25 by about 25%. This margin can well cover the contribution to the shear due to the higher mode effect, as discussed previously.

From the above comparison, it can be concluded that the use of a uniform inertia load with the magnitude of the averaged floor spectral acceleration at the fundamental mode, provides a good approximation for calculating the seismic response in the wall panel.

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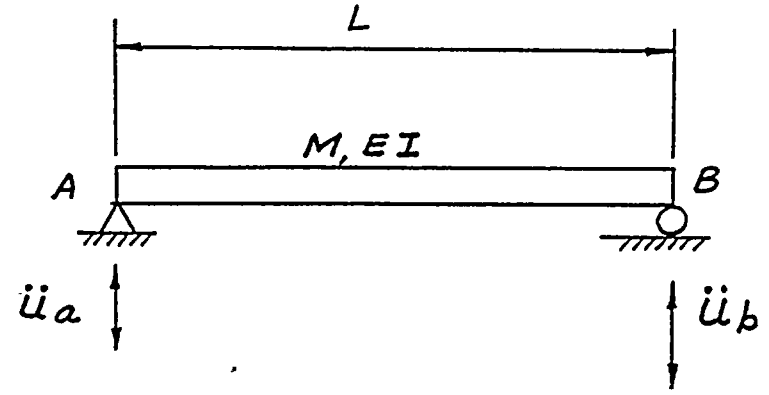
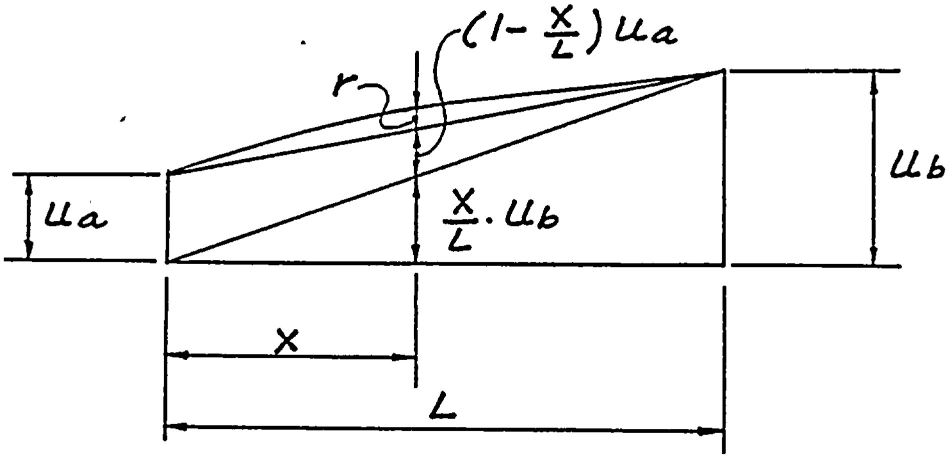


IDEALIZED SIMPLY-SUPPORTED UNIFORM BEAM

FIGURE No 1



RELATION BETWEEN SEISMIC EXCITATION AND RELATIVE DISPLACEMENT

FIGURE No 2

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ENCLOSURE 2

TYPICAL WALL FIXES

TYPE 1
TYPE 2
TYPE 3
TYPE 4

WP26/15-12

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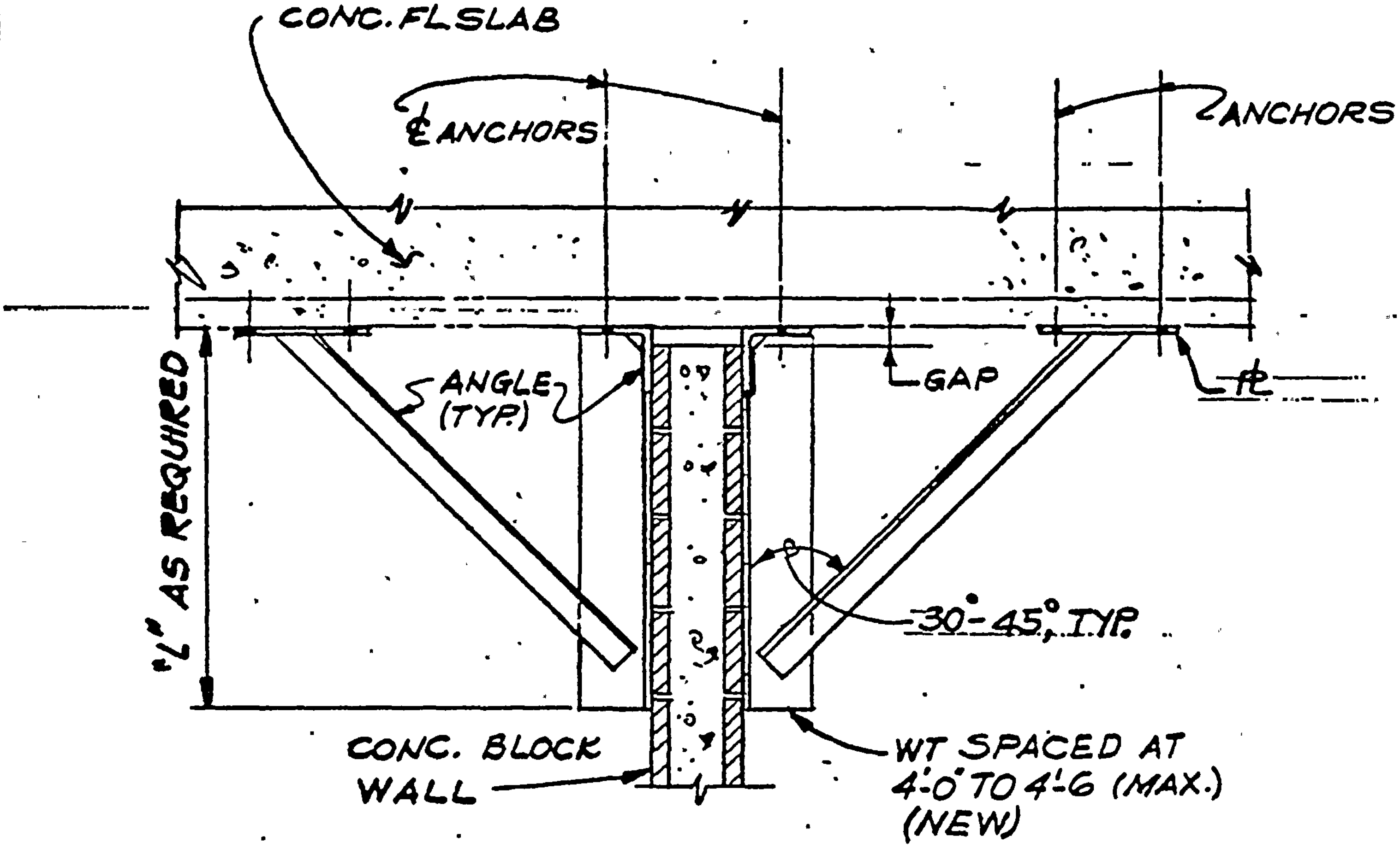
REVISION - 1



TYPE 1

ANGLE BRACING TO CONCRETE

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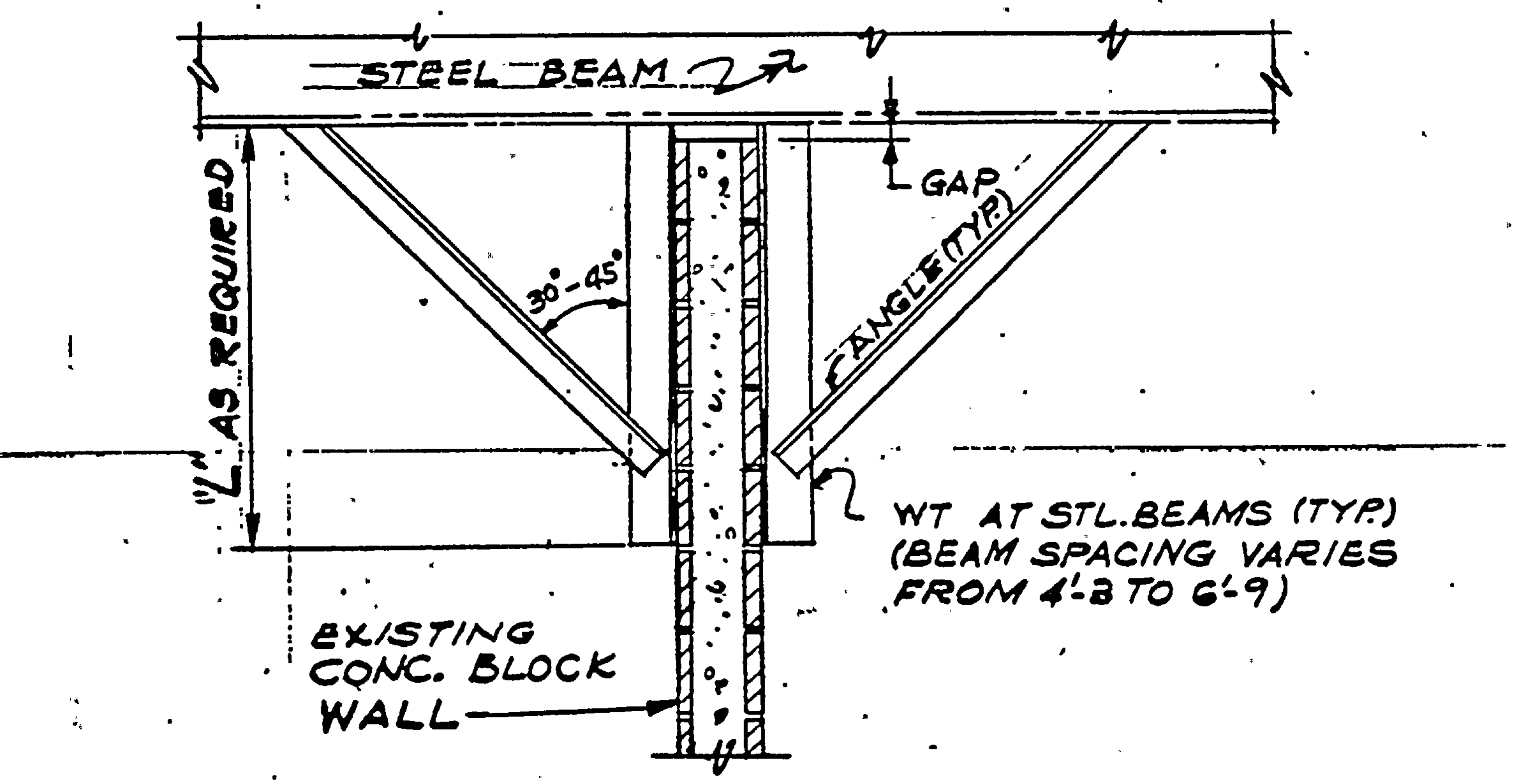
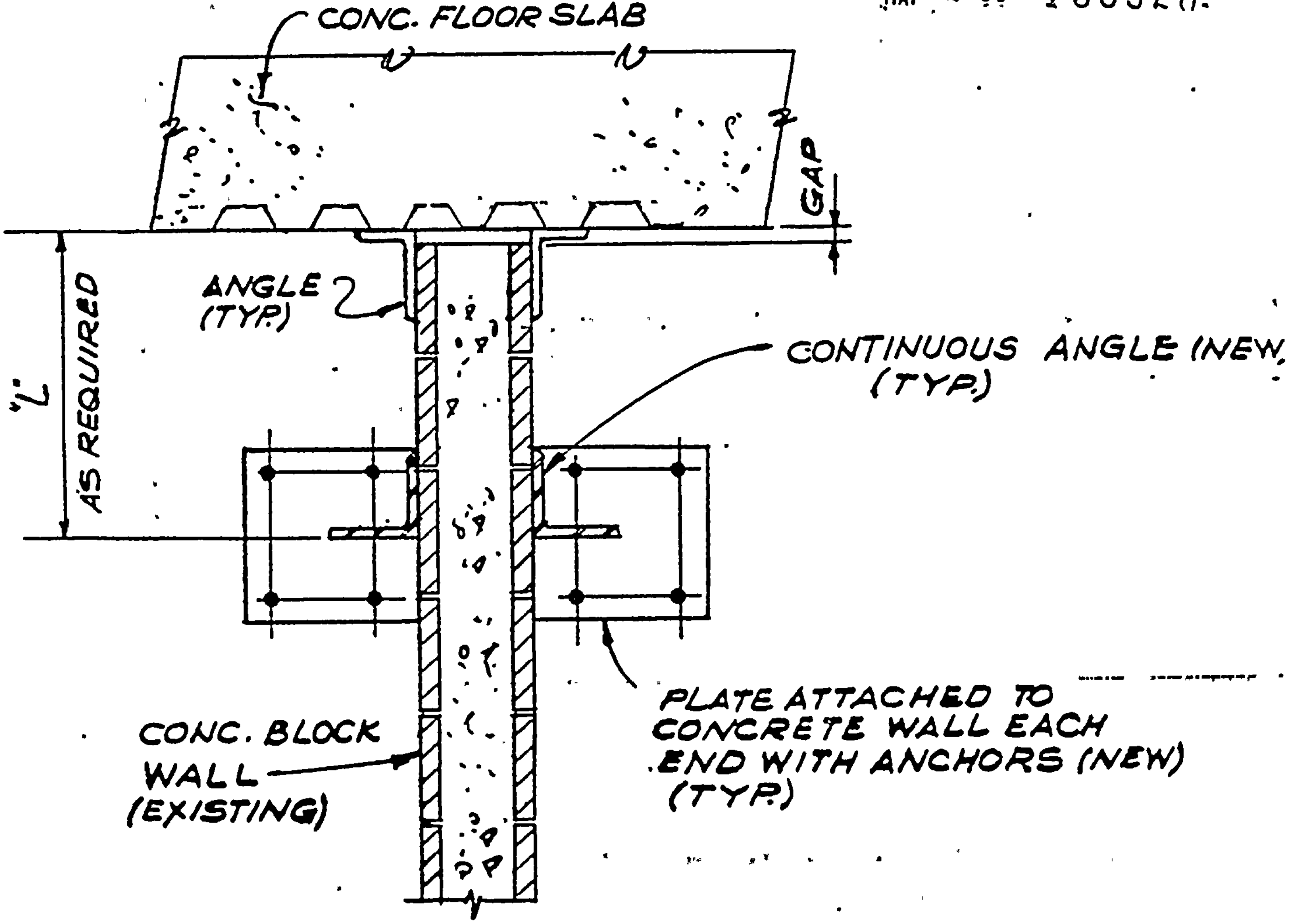
REVISION - 1



TYPE 2

ANGLE BRACING TO STEEL



TYPE 3

CONTINUOUS ANGLE

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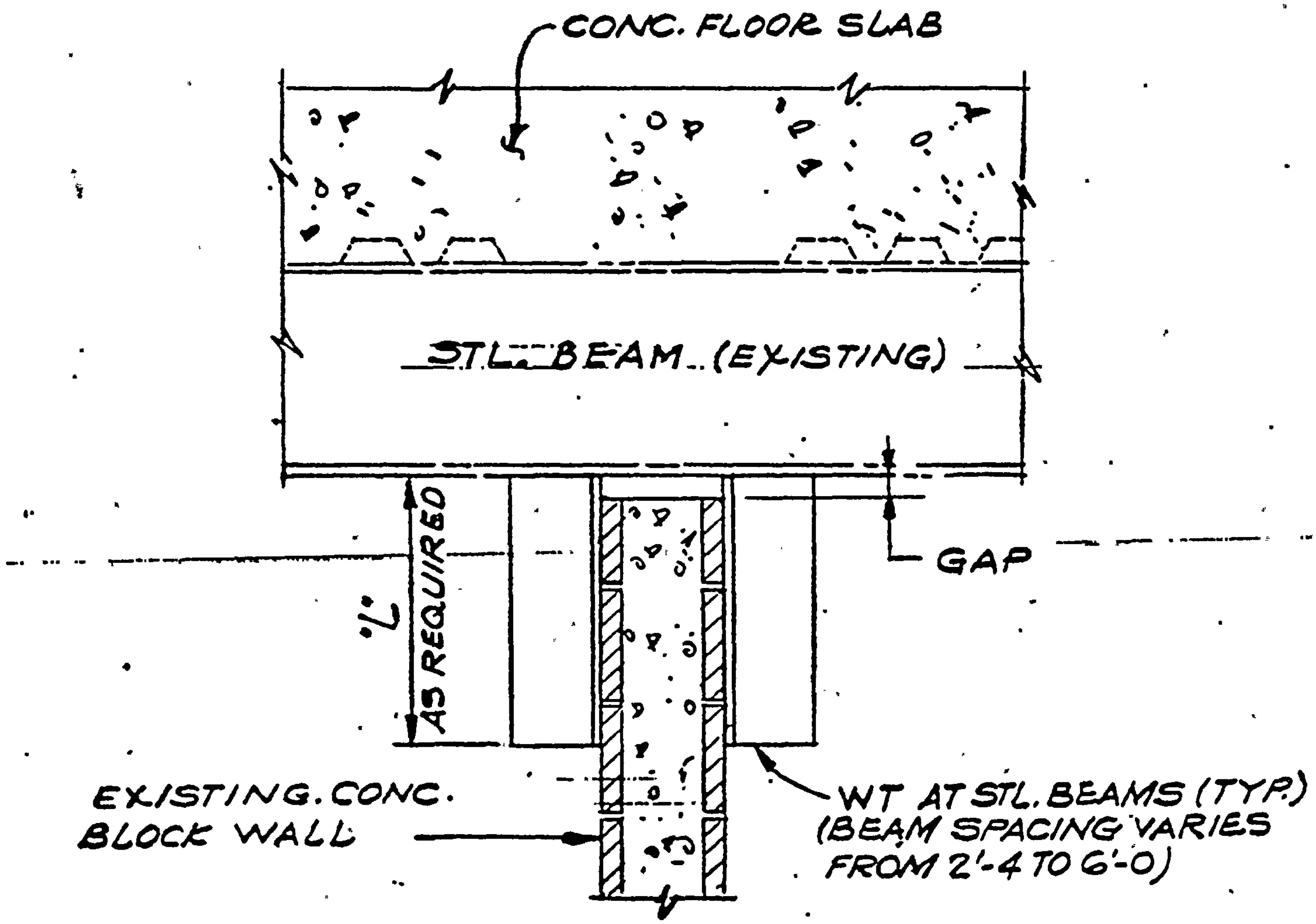
REVISION - 1



TYPE 4

INTERMITTENT SUPPORTS