Proposed draft for IS 1893 on design of non-structural elements

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Seismic safety of non-structural elements is no less important than that of supporting structures as their survival is essential to provide emergency and recovery services in the aftermath of an earthquake. Therefore, non-structural elements should be designed to resist the seismic forces or seismic relative displacements depending on their nature. Indian seismic code IS 1893 (Part 1): 2002 does not have specific provisions on design of non-structural elements and their connections or attachments. A companion paper[1], published earlier, reviewed the design philosophy and design provisions on non-structural elements contained in several international seismic codes. This paper contains proposed provisions for inclusion in IS 1893, detailed commentary of the proposed clauses as well as some solved examples of the seismic design of non-structural elements.

Keywords: *Non-structural elements, seismic design, relative displacement, acceleration sensitive, deformation sensitive.*

It is necessary to design non-structural elements to resist seismic forces or seismic relative displacements. Hence, new provisions on seismic design of non-structural components and their attachments are proposed in this paper for inclusion in IS 1893. Comments regarding the proposed provisions are also given. Several parameters have been considered, for example, dynamic amplification of the component relative to the fundamental period of structure; ductility, redundancy, and energy dissipation capacity of the element and its attachment to the structures; vertical location of the element in the building; importance and weight of the non-structural element itself. Displacement provisions are similar to those of IBC 2003[2]. Two types of displacement equations are provided: two connection points on the same structure and two connection points on the different structures. This paper also shows the application of these provisions for equipment, equipment supported on vibration isolator, and for a displacement sensitive element like sign board through solved examples.

*C denotes commentary

This paper contains proposed provisions for possible inclusion in IS 1893 along with detailed commentary on the proposed clauses as given by the authors. The feedback / discussion on the proposed provisions may be directed to the NICEE (www.nicee.org) at IIT Kanpur by e-mail (nicee@iitk.ac.in). ICJ would be pleased to publish the summary of these discussions at a later date.

Proposed provision for IS 1893[3]

Non-structural elements

1.1 General

1.1.1

This section establishes minimum design criteria for the non-structural components of architectural, mechanical, and electrical systems permanently installed in buildings, including supporting structures and attachments.

C 1.1.1*

In several past earthquakes, it is seen that failure of non-structural elements posed safety risk to building occupants, and critically impaired the performance of the buildings as well as that of, for example, fire and police stations, power stations, communication facilities and water supply. Moreover, in most of the buildings, non-structural elements represent a high percentage of the total cost of the buildings. Therefore, nowadays it is widely recognised that good performance of non-structural elements during earthquakes is extremely important.

1.1.2

This section is not applicable where a non-structural component directly modifies the strength or stiffness of the building structural elements, or its mass affects the building loads. In such a case, its characteristics should be considered in the structural analysis of the building.

C 1.1.2

When the non-structural element significantly affects structural response of the building, the non-structural component should be treated as structural, and the relevant structural provisions should apply. For example, in general, a masonry infill wall should be considered as structural for in-plane response, and therefore, it is within the scope of a separate new section to be added in the code on infilled systems.

1.1.3

For non-structural elements of great importance or of a particular dangerous nature, the seismic analysis should be based on the floor response spectra derived from the response of the main structural system.

1.1.4

Particular care should be taken to identify masonry infill that could reduce the effective length of adjoining columns.

C 1.1.4

Partial infill of masonry walls between columns may create short-column effect, that is, reduce the effective length of the column, and seriously affect the building response.

1.1.5

In general, if the component weight exceeds 20 percent of the total dead weight of the floor, or exceeds 10 percent of the total weight of the structure provisions in this section should not be used.

1.2 Classification

Depending on response sensitivity, non-structural elements can be classified as deformation sensitive, acceleration sensitive, or both deformation and acceleration sensitive. *Table* 1 classifies non-structural elements according to their response sensitivity.

1.2.1

Acceleration sensitive non-structural elements should be designed according to the force provisions contained in clause 1.3.

C 1.2.1

Non-structural components are regarded as acceleration sensitive when they are mainly affected by acceleration of the supporting structure. In such a case, structural-non-structural interaction due to deformation of the supporting structure is not significant. Acceleration sensitive non-structural components are vulnerable to sliding, overturning, or tilting. Mechanical and electrical components are generally acceleration sensitive.

Table 1(a): Response sensitivity of architectural components (clause 1.2)[4]

No	*Component*	*Sensitivity Acc*	*Sensitivity Def*
1.	Exterior skin		
	Adhered veneer	S	P
	Anchored veneer	S	P
	Glass blocks	S	P
	Prefabricated panels	S	P
	Glazing systems	S	P
2.	Partitions		
	Heavy	S	P
	Light	S	P
3.	Interior veneers		
	Stone, including marble	S	P
	Ceramic tile	S	P
4.	Ceilings		
	Directly applied to structure	P	
	Dropped, furred, gypsum board	P	
	Suspended lath and plaster	S	P
	Suspended integrated ceiling	S	P
5.	Parapets and appendages	P	
6.	Canopies and marquees	P	
7.	Chimneys and stacks	P	
8.	Stairs	P	S

Table 1(b): Response sensitivity of mechcanical components (clause 1.2)[4]

No	*Component*	*Sensitivity Acc*	*Sensitivity Def*
1.	Mechanical equipment		
	Boilers and furnaces	P	
	General manufacturing and process machinery	P	
	HVAC Equipment, vibration isolated	P	
	HVAC equipment. non-vibration isolated	P	
	HVAC equipment, mounted in-line with ductwork	P	
2.	Storage vessels and water heaters		
	Structurally supported vessels	P	
	Flat bottom vessels	P	
3.	Pressure piping	P	S
4.	Fire suppression piping	P	S
5.	Fluid piping, not fire suppression		
	Hazardous materials	P	S
	Non-hazardous materials	P	S
6.	Ductwork	P	S

Note: Acc = Acceleration sensitive; Def = Deformation sensitive; *P* = Primary response; *S* = Secondary response

1.2.2

Deformation sensitive non-structural elements should be designed according to the provisions contained in clause 1.4.

C 1.2.2

Non-structural components are regarded as deformation sensitive when they are affected by supporting structure's deformation, especially the inter-storey drift. Good performance of deformation sensitive non-structural elements can be ensured in two ways[5]:

(i) by limiting inter-storey drift of the supporting structure in case of important non-structural elements

(ii) by designing the element to accommodate the expected lateral displacement without damage.

1.2.3

Some components may be both acceleration and deformation sensitive, but generally one or the other of these characteristics is dominant, *Table* 1. They must be analysed for both forms of response, that is, as per provisions 1.3 and 1.4.

1.3 Design seismic force

1.3.1

Design seismic force, F_p, on the non-structural element should be calculated using the following expression

$$F_p = \frac{Z}{2}\left(1+\frac{x}{h}\right)\frac{a_p}{R_p} I_p W_p$$

$$\geq 0.10 W_p$$

where,

- Z = zone factor given in *Table* 2 of IS 1893 (part 1): 2002[3]
- x = height of point of attachment of the non-structural element above the foundation
- h = height of the structure
- a_p = component amplification factor given in *Tables* 2 and 3
- R_p = component response modification factor given in *Tables* 2 and 3
- I_p = importance factor of the non-structural element given in *Table* 4
- W_p = weight of the non-structural element.

C 1.3.1

The component amplification factor, a_p, represents the dynamic amplification of the component relative to the fundamental period of structure. In most situations, the non-structural element may need to be designed without fundamental period of the structure being available. Further, one may need to carry out experimental studies (for example, shake table study) to evaluate fundamental period of the non-structural element which may not be feasible.

The component response modification factor, R_p, represents ductility, redundancy, and energy dissipation capacity of the element and its attachment to the structures. Not much research is available on evaluation of these factors.

Hence, values of, a_p and R_p, *Tables* 2 and 3 are taken same as in NEHRP provisions[6]; these empirically specified values are based on "collective wisdom and experience of the responsible committee".

In choosing these values, it is expected that the component will behave as either flexible (a_p =2.5) or rigid (a_p =1.0) body. In general, values of R_p are taken as 1.5, 2.5 and 3.5 for low, limited and high deformable structures, respectively.

Input acceleration at the point of attachment depends on peak ground acceleration, dynamic response of the building, and the location of the element along the height of the building. In this equation, the input acceleration at the point of attachment has been approximated as linearly varying from the acceleration at the ground (0.5Z) to the acceleration at the roof *(Z)*.

A lower limit of F_p is set to assure a minimal seismic design force.

Table 2: Coefficients for architectural components (clause 1.3)

Architectural component or element	a_p*	R_p
Interior non-structural walls and partitions		
Plain (unreinforced) masonry walls	1.0	1.5
All other walls and partitions	1.0	2.5
Cantilever elements (unbraced or braced to structural frame below its centre of mass)		
Parapets and cantilever interior non-structural walls	2.5	2.5
Chimneys and stacks where laterally supported by structures	2.5	2.5
Cantilever elements (braced to structural frame above its centre of mass)		
Parapets	1.0	2.5
Chimneys and stacks	1.0	2.5
Exterior non-structural walls	1.0	2.5
Exterior non-structural wall elements and connections		
Wall element	1.0	2.5
Body of wall panel connection	1.0	2.5
Fasteners of the connecting system	1.25	1.0
Veneer		
High deformability elements and attachments	1.0	2.5
Low deformability and attachments	1.0	1.5
Penthouses (except when framed by and extension of the building frame)	2.5	3.5
Ceilings		
All	1.0	2.5
Cabinets		
Storage cabinets and laboratory equipment	1.0	2.5
Access floors		
Special access floors	1.0	2.5
All other	1.0	1.5
Appendages and ornamentations	2.5	2.5
Signs and billboards	2.5	2.5
Other rigid components		
High deformability elements and attachments	1.0	3.5
Limited deformability elements and attachments	1.0	2.5
Low deformability elements and attachments	1.0	1.5
Other flexible components		
High deformability elements and attachments	2.5	3.5
Limited deformability elements and attachments	2.5	2.5
Low deformability elements and attachments	2.5	1.5

*A lower value for a_p is permitted provided a detailed dynamic analysis is performed which justifies a lower value. The value for a_p shall not be less than 1.0. The value of a_p=1.0 is for equipment generally regarded as rigid and rigidly attached. The value of a_p=2.5 is for flexible components or flexibly attached components.

1.3.2

For vertical non-structural elements, F_p, will be the horizontal force, and for horizontal non-structural elements, F_p, will be the vertical force.

C 1.3.2

No distinction is being made between the horizontal and the vertical vibrations of the ground and of the structure, considering many other approximations involved.

1.3.3

For a component mounted on a vibration isolation system the design force shall be taken as $2F_p$.

Table 3: Coefficients for mechanical and electrical components (clause 1.3)

Mechanical and electrical component or element	a_p**	R_p
General mechanical		
Boilers and furnaces	1.0	2.5
Pressure vessels on skirts and free-standing	2.5	2.5
Stacks	2.5	2.5
Cantilevered chimneys	2.5	2.5
Others	1.0	2.5
Manufacturing and process machinery		
General	1.0	2.5
Conveyors (non-personnel)	2.5	2.5
Piping systems		
High deformability elements and attachments	1.0	2.5
Limited deformability elements and attachments	1.0	2.5
Low deformability elements and attachments	1.0	1.5
HVAC system equipment		
Vibration isolated	2.5	2.5
Non-vibration isolated	1.0	2.5
Mounted in-line with ductwork	1.0	2.5
Other	1.0	2.5
Elevator components	1.0	2.5
Escalator components	1.0	2.5
Trussed towers (free-standing or guyed)	2.5	2.5
General electrical		
Distributed systems (bus ducts, conduit, cable tray)	2.5	5.0
Equipment	1.0	1.5
Lighting fixtures	1.0	1.5

**A lower value for a_p is permitted provided a detailed dynamic analysis is performed which justifies a lower value. The value for a_p shall not be less than 1.0. The value of a_p = 1.0 is for equipment generally regarded as rigid and rigidly attached. The value of a_p = 2.5 is for flexible components or flexibly attached components.

C 1.3.3

A vibration isolated component can experience higher seismic accelerations than in the case where the same component is rigidly mounted. This is due to the amplification effects of the vibration mounts. The fundamental period of the isolated components can be such that resonance condition with one or more modes of the primary structure is possible. This can result in amplification in lateral force.

1.3.4 – Connections

Connections and attachments or anchorage of the non-structural element should be designed for twice the design seismic force required for that non-structural element. Connection and attachment shall be bolted, welded, or otherwise positively fastened without consideration of frictional resistance produced by the effect of gravity. Connections to ornaments, veneers, appendages, and exterior panels including anchor bolts shall be corrosion resisting, ductile, and have adequate anchorages.

C 1.3.4

Friction forces induced by gravity should be ignored, because vertical ground motions may reduce the effect of gravity.

1.4 Seismic relative displacement

Seismic relative displacement, D_p, that a non-structural element must be designed to accommodate shall be determined as per clauses 1.4.1, 1.4.2 and 1.4.3.

C 1.4

Seismic relative displacement equations are provided to support the selection and design of cladding, stairwells, piping systems, sprinkler systems, and other components that are connected to the building at multiple levels (clause 1.4.1) or to adjacent buildings (clause 1.4.2). These equations provide the architect a rational basis for assessing the flexibility or clearances required by components and claddings and their connections to accommodate the expected building movements during earthquake.

1.4.1

For two connection points on the same structure A, one at a height h_x, and other at a height h_y, seismic relative displacement shall be determined as:

$$D_p = \delta_{xA} - \delta_{yA}$$

D_p is not required to be taken as greater than

$$R\left(h_x - h_y\right)\frac{\Delta_{aA}}{h_{sx}}$$

where,

δ_{xA} = deflection at building level x of structure A due to design seismic load determined by elastic analysis, and multiplied by response reduction factor (R) of the building as per Table 7 of IS 1893 (part 1): 2002[3]

δ_{yA} = deflection at building level y of structure A due to design seismic load determined by elastic analysis, and multiplied by response reduction factor (R) of the building as per Table 7 of IS 1893 (part 1): 2002[3]

h_x = height of level x to which upper connection point is attached

h_y = height of level y to which lower connection point is attached

Δ_{aA} = allowable storey drift for structure A calculated as per 7.11.1 of IS 1893 (part 1): 2002[3]

h_{sx} = storey height below level x.

C 1.4.1

The first equation yields an estimate of actual structural displacements, as determined by elastic analysis, with no structural-response modification factor, R. Second equation is provided in recognition that elastic displacements are not always defined or available at the time the component is designed or procured. This equation allows the use of storey drift limitations.

1.4.2

For two connection points on separate structures A and B, or separate structural systems, one at height, h_x, and the other at a height, h_y, D_p shall be determined as:

$$D_p = \left|\delta_{xA}\right| + \left|\delta_{yB}\right|$$

D_p is not required to be taken as greater than

$$R\left(h_x\frac{\Delta_{aA}}{h_{sx}} + h_y\frac{\Delta_{aB}}{h_{sx}}\right)$$

where,

δ_{yB} = deflection at building level y of structure B due to design seismic load determined by elastic analysis, and multiplied by response reduction factor, R, of the building as per Table 7 of IS 1893 (part 1): 2002[3],

Δ_{aB} = allowable storey drift for structure B calculated as per 7.11.1 of IS 1893 (part 1): 2002[3].

1.4.3

The effect of seismic relative displacements shall be considered in combination with displacements caused by other loads as appropriate.

C 1.4.3

Seismic relative displacements must be combined with the displacements due to other loads such as thermal and static loads.

Examples

Some typical examples and their solutions are given in the *Appendix* to illustrate the analysis and design of non-structural elements.

Conclusions

In recent years, there is a considerable interest in seismic design of non-structural elements to reduce loss of functionality and financial losses. IS 1893 (part 1): 2002 lacks provisions for the seismic design of non-structural elements. Therefore, a draft for provisions for IS 1893 on non-structural elements is presented in this paper. The force-sensitive elements need to be designed to withstand seismic design force while acceleration sensitive elements must be designed to accommodate seismic relative displacement. Detailed commentary and solved examples of different types of non-structural elements are also presented.

Acknowledgements

The work reported in this paper has been supported through a project entitled "Review of Building Codes and Preparation of Commentary and Handbooks" awarded to IIT Kanpur by Gujarat State Disaster Management Authority (GSDMA), Gandhinagar through World Bank finances. The views and opinions expressed therein are those of the authors and not necessarily those of the GSDMA or the World Bank.

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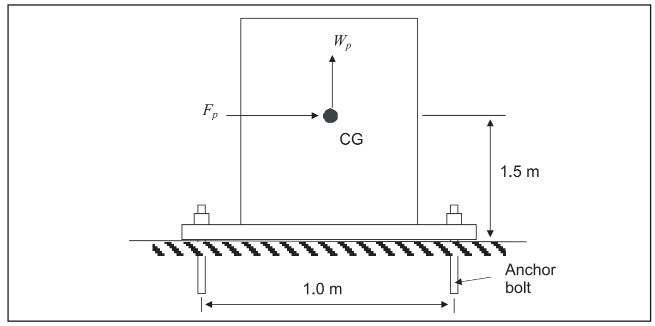

Fig 1 Equipment installed at roof

Appendix : Three examples

Example 1: Design for anchorage of an equipment

Problem statement

A 100 kN equipment, *Fig* 1, is to be installed on the roof of a five storey building in Simla (seismic zone IV). It is attached by four anchored bolts, one at each corner of the equipment, embedded in a concrete slab. Floor to floor height of the building is 3.0 m except the ground storey which is 4.2 m. Determine the shear and tension demands on the anchored bolts during earthquake shaking.

Solution

Zone factor, Z = 0.24 (for zone IV, *Table* 2 of IS 1893 (part 1): 2002[3])

Height of point of attachment of the equipment above the foundation of the building,

$x = (4.2 + 3.0 \times 4)$ m = 16.2 m

Height of the building, h = 16.2 m

Amplification factor of the equipment, a_p =1 (rigid component, *Table* 3),

Response modification factor R_p = 2.5 (*Table* 3),

Importance factor I_p =1 (not life safety component, *Table* 4),

Weight of the equipment, W_p =100 kN

The design seismic force, $F_p = \frac{Z}{2}\left(1+\frac{x}{h}\right)\frac{a_p}{R_p} I_p W_p$

$$= \frac{0.24}{2}\left(1+\frac{16.2}{16.2}\right)\frac{1.0}{2.5}\times 1\times 100\,\text{kN}$$

$$= 9.6\,\text{kN} < 0.1W_p = 10.0\,\text{kN}$$

Hence, design seismic force, for the equipment

F_p = 10.0 kN.

The anchorage of equipment with the building must be designed for twice this force (Clause 1.3.4)

Shear per anchor bolt,

$$V = \frac{2F_p}{4}$$

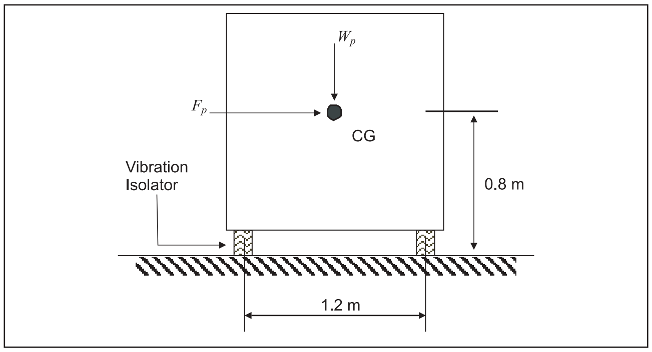

Fig 2 Electrical generator installed on the floor

$$= 2\times\frac{10.0}{4}\ \text{kN}$$
$$= 5.0\ \text{kN}$$

The overturning moment is

$$M_{ot} = 2.0\times10.0\ \text{kN}\times1.5\ \text{m}$$
$$= 30.0\ \text{kN-m}$$

The overturning moment is resisted by two anchor bolts on either side. Hence, tension per anchor bolt from overturning is

$$F_t = \frac{30.0}{1.0\times2}\ \text{kN}$$
$$= 15.0\ \text{kN}$$

Example 2: Anchorage design for an equipment supported on vibration isolator

Problem statement

A 100 kN electrical generator of a emergency power supply system is to be installed on the fourth floor of a 6-storey hospital building in Guwahati (zone V). It is to be mounted on four flexible vibration isolators, one at each corner of the unit, to damp the vibrations generated during the operation, *Fig* 2. Floor to floor height of the building is 3.0 m. except the ground storey which is 4.2 m. Determine the shear and tension demands on the isolators during earthquake shaking.

Solution

Zone factor, Z = 0.36 (for zone V, Table 2 of IS 1893 (part 1): 2002[3]),

Height of point of attachment of the generator above the foundation of the building,

$$x = (4.2 + 3.0 \times 3)\ \text{m}$$
$$= 13.2\ \text{m},$$

Height of the building,

$$h = (4.2 + 3.0 \times 5)\ \text{m}$$
$$= 19.2\ \text{m}$$

Amplification factor of the generator, a_p = 2.5 (flexible component, *Table* 3),

Response modification factor R_p= 2.5 (vibration isolator, *Table* 3),

Importance factor I_p = 1.5 (life safety component, *Table* 4),

Table 4: Importance factor, I_p , of non-structural elements (clause 1.3)

Description of non-structural element	I_p
Component containing hazardous contents	1.5
Life safety component required to function after an earthquake (for example, fire protection sprinklers system)	1.5
Storage racks in structures open to the public	1.5
All other components	1.0

Weight of the generator, W_p = 100 kN

The design lateral force on the generator,

$$F_p = \frac{Z}{2}\left(1+\frac{x}{h}\right)\frac{a_p}{R_p}I_pW_\text{P}$$

$$= \frac{0.36}{2}\left(1+\frac{13.2}{19.2}\right)\frac{2.5}{2.5}(1.5)(100)\text{kN}$$

$$= 45.6\ \text{kN} > 0.1W_p = 10.0\ \text{kN}$$

Since the generator is mounted on flexible vibration isolator, the design force is doubled, that is,

$$F_p = 2 \times 45.6\ \text{kN}$$
$$= 91.2\ \text{kN}$$

Shear force resisted by each isolator,

$$V = F_p/4$$
$$= 22.8\ \text{kN}$$

The overturning moment,

$$M_{ot} = (91.2\ \text{kN}) \times (0.8\text{m})$$
$$= 73.0\ \text{kN-m}$$

The overturning moment, M_{ot}, is resisted by two vibration isolators on either side. Therefore, tension or compression on each isolator:

$$F_t = \frac{73}{1.2\times2}\ \text{kN}$$
$$= 30.4\ \text{kN}$$

Example 3: Design of a large sign board attached to a building

Problem statement

A neon sign board is attached to a 5-storey building in Ahmedabad (seismic zone III). It is attached by two anchors at a height 12.0 m

Corrigendum

In the paper titled "Design of non-structural elements for buildings: A review of codal provisions" by Goutam Mondal and Sudhir K. Jain published in theAugust 2005 issue, Vol. 79, No. 8, pp. 22-28, the left-hand side of equation (10) did not get printed through oversight. The correct equation should be read as:

$$F_{ph} = C_{ph}W_pR_p \qquad ...(10)$$

The error is regretted. — *Editor*

and 8.0 m. From the elastic analysis under design seismic load, it is found that the deflections of upper and lower attachments of the sign board are 35.0 mm and 25.0 mm, respectively. Find the design relative displacement.

Solution

Since sign board is a displacement sensitive non-structural element, it should be designed for seismic relative displacement.

Height of level x to which upper connection point is attached, h_x = 12.0 m

Height of level y to which lower connection point is attached, h_y = 8.0 m

Deflection at building level x of structure A due to design seismic load determined by elastic analysis = 35.0 mm

Deflection at building level y of structure A due to design seismic load determined by elastic analysis = 25.0 mm

Response reduction factor of the building R = 5 (special RC moment-resisting frame, *Table* 7 of IS 1893 (part 1): 2002[3])

$$\delta_{xA} = 5\times 35 = 175.0 \text{ mm}$$

$$\delta_{yA} = 5\times 25 = 125.0 \text{ mm}$$

(*i*) $D_p = \delta_{xA} - \delta_{yA}$

$= (175.0 - 125.0)$ mm

$= 50.0$ mm

Design the connections of neon board to accommodate a relative motion of 50 mm.

(*ii*) Alternatively, assuming that the analysis of building is not possible to assess deflections under seismic loads, one may use the drift limits (this presumes that the building complies with seismic code).

Maximum inter-storey drift allowance as per clause 7.11.1 of IS 1893 (part 1): 2002[3] is 0.004 times the storey height, that is:

$$\frac{\Delta_{aA}}{h_{sx}} = 0.004$$

$$D_p = R\left(h_x - h_y\right)\frac{\Delta_{aA}}{h_{sx}}$$

$= 5\ (12000.0 - 8000.0)(0.004)$ mm

$= 80.0$ mm

The neon board will be designed to accommodate a relative motion of 80 mm.

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