# DESIGN PRINCIPLES OF EARTHQUAKE RESISTANT BLAST FURNACES.-

by Rodrigo Flores (1)

## Abstract :

The Compañía de Acero del Pacífico, CAP decided recently to construct a second blast furnace in its Huachipato Steel Plant near Concepción, Chile, located in an area of high seismicity. A critical reappraisal of the solution given to earthquake resistant problems in blast furnaces design in Chile and abroad is given.

## 1.- Introduction.-

Industrial development in earthquake regions implies special problems of structural design. This is the case for Chile where industries have been installed in recent years even in areas of high seismicity.

Design of special structures such as blast furnaces involves unusual problems due to scarcity of data caused by insufficient experience under seismic conditions and by the lack of systematic research from earthquake engineering viewpoint. The case of building design is quite different since a strong tradition of design and wide experience with destructive earthquake is available.

Figure 1 shows in a schematic form the installation of a blast furnace with its accesory equipment and the corresponding flow diagram. The earthquake design of the blast furnace unit includes various structures; however, in the following we shall discuss the blast furnace itself including the pipes that connect it with other structures. The figure shows the approximate general layout of the installations of the second blast furnace at Huachipato, 10 Km. West of Concepcion, owned by Compañía de Acero del Pacífico CAP. The present paper discusses the design principles of this new blast furnace. The blast furnace N°1 of CAP, of 1200 MT per day, capacity, was in operation at the time of the devasting earthquake which affected the area in May 1960.

## 2.- Special conditions of the problem.-

Before entering upon the subject proper, let us emphasize the enormous empirism to be found in explaining the internal processes in a blast furnace. For example considering that part of the processes with structural implications only, the manner of support of the internal burden is not perfectly known. Obviously one part must be trasmitted by friction and mechanical interlooking with the walls, while the rest acts as a vertical column. The latter in turn appears to float in a liquid bath of molten pig iron and slag. The pressure of the order of 25 psi injected through the tuyeres builds up a regime of internal pressure which decreases with height, thus adding a new factor in the vertical equilibrium relatioship. Wall pressures, the physical state and density of the burden are not constant with height and even at any given point they may change with time depending upon the cycle of the blast furnace. Perfect symmetry of loads and pressures as

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referred to a vertical axis cannot be assumed either, because the loads may slide down more rapidly on one side than on another. Finally the structural function of the heavy refractory lining is very difficult to determine in quantitative terms.

The problems outlined above when translated in dynamical terms signify that great caution must be exercised in selecting a physical model to represent reality. Frequently a method of succesive computations involving different loads assumption will be necessary in order to select a design for the envelope of maximum values. A further difference between earthquake resistant design in blast furnaces and in buildings is due to the fact that damage must be prevented in the pipes and their connection to the blast furnace in addition to the structure itself, since such damage may result in fire and even explosion hazards.

## 3.- Preliminary information on design.-

As a preliminary to the design of a blast furnace we have studied local and foreign experience. Regarding the latter only Japanese references are available, thus giving an indication of the recent nature of the problem.

As present in Japan a design based upon the addition of a rigid resisting frame is becoming widespread. This design is similar to the structural solution of blast furnaces adopted in Germany. Surrounding the blast furnace is a structure of rigid frames which lend vertical and lateral support to the upper part of the furnace including the top cone. The furnace structure itself is self-supporting. The upper section including the skip loading mechanism, gas collecting pipes, downcomers to the dustcatcher, platforms, etc., are vertically and laterally supported by the rigid frame (Fig. 2). Since the upper part of the blast furnace is supported by the lateral frame and the furnace itself is free, it becomes necessary to provide a gas sealed joint at the upper part of the furnace. In the Japanese design this is provided for by the expansion joint as shown. This joint may easily take care of vertical displacements; however, for the horizontal displacements it is not clear whether its flexibility will be sufficient to provide for its use without damage. In Japan in addition to seismic forces,horizontal design against typhoons is of great importance. This wind load is so high in the upper part of the furnace (about 500 Kg/m2) that the structure is often designed for seismic forces in the furnace itself and for wind loads in its upper section. These important loads make the moment connection between the upper part and the shell of the furnace rather critical. This justifies the existence of an additional structure such as the outer frame to support the upper section loads. No Japanese blast furnace has been subjected to the trial of a destructive earthquake as far as we know. The blast furnace N°1 at Huachipato which constitute the object of the following comments was tested by the earthquake of May 1960. This blast furnace was specially design against earthquake forces in 1946 by the engineering firm of Brassert Co., in close cooperation with CAP engineers. The structure was inspired by a conventional American design which has been considerably reinforced to resist horizontal forces. The main lateral resisting elements of the structure include the shell and a space frame composed by a box-type ring beam supported by box-type columns. At the lower base level a second box-type ring beam is anchored to the concrete foundation. The bosch has ring bands connected in such a way that it is not in itself resistant to horizontal forces (Fig. 3).

The wide flange of the column of the conventional American type furnace has been replaced by a box-type section which is better suited to resist the compression and bending regime induced by earthquake action. A balanced design of columns has been obtained by providing a degree of fixity at the upper section. The columns are restrained in a radial direction by the torsional stiffness of the box-type beam. The connections of the columns to the upper and lower rings are obtained in a functional manner by providing curved haunches suited to a smooth stress flow, owing to the use of box sections both in columns and rings. A practical solution for anchoring the structure to the foundation is obtained by providing a large contact section between the lower ring and the concrete. In this solution the shell acts like a stack supported by the space frame. All the upper elements are rigidly connected to the shell. The structure was designed for a seismic factor of 17%. The structure successfully resisted the earthquake of May 1960 with an intensity VIII on the modified Mercalli scale. Only minor damage was produced in the upper connection of the skip bridge with the top platforms.

## 4.- Design solution for the second blast furnace at Huachipato.-

If we trace the evolution of the two solutions described above, we find that both designs are derived fron structural types developed in non-seismic regions with earthquake resistance added. Thus the Japanese design derives from the German, whereas the Chilean derives from the American conventional design. Both solutions have their advantages and drawbacks, some of which have already been mentioned. Since the Huachipato area is not subjected to strong winds and the Japanese design does not seem justified for this reason, the final decision favored a similar structure to the one that exists in the first blast furnaces. The good behaviour of this structural type in the May 1960 earthquake was a factor in favor of this decision. The design of the second blast furnace is being carried out by Koppers Co. with the assistance of CAP Engineering Department and the writer.

## 5.- Structural design of the blast furnace.-

Some of the special design problems of the new blast furnace are as follows :

a) Interaction between the top ring of the space frame and the shell for determining the rigidity of the frame;

b) Special effects on the resistance of the structure due to the openings for cooling plates which make it necessary to reinforce the sections;

c) Sliding joint of the bosch jacket with the top ring and the shell. This sliding joint was made necessary due to differential deformations caused by thermal effects and should allow vertical movement of the bosch jacket while providing lateral support on the ring during earthquake action;

d) Effect of the refractory lining, disregarded for strength purposes but which is taken into account for its damping properties;

e) Earthquake effects on pipes with special attention on the need for absorbing displacements between connecting points due to earthquake action.

The structure will be analyzed according to two earthquake resistant design procedures : dynamic method and equivalent static method.

## 5.1 Dynamic analysis.-

Dynamic analysis will be carried out by the so-called modal analysis based on the knowledge of elastic properties and mass distribution of the structure and assuming a response spectrum curve for the locality. Figure 4 shows the assumed simplified structure with all the resistant elements mentioned above. Lumped masses $m_1$ and $m_2$ and distributed masses $\mu_1$ and $\mu_2$ are shown. A massless rod is introduced which carries at its end a concentrated mass $m_2$ representing all the masses located above the top of the furnace. The rod is assumed non-deformable and is rigidly connected at the top of the blast furnace. Thus the angular deflection at the top of the furnace is transmitted to the rod. This condition defines the length of the rod $h^1$. The concentrated mass $m_1$, at the upper end of the columns represents all the masses located at that level plus the fraction of columns masses which it is necessary to concentrate at their upper level to give the dynamic equivalent between the space frame and the spring of rigidity k. The distributed masses $\mu_1$ and $\mu_2$ represent masses per unit length corresponding to the masses of the steel plates, refractory lining and burden. The shell as well as the bosch and hearth jackets are assumed to deform by bending only. The structural diagram is shown in Fig. 5 and may be described by the following equations :

$$\frac{\partial^2}{\partial x^2}\left(EI\,\frac{\partial^2 y_1}{\partial x^2}\right) = -\mu_1\,\frac{\partial^2 y_1}{\partial t^2} \qquad (0 < x < h_1)$$

$$\frac{\partial^2}{\partial x^2}\left(EI\,\frac{\partial^2 y_2}{\partial x^2}\right) = -\mu_2\,\frac{\partial^2 y_2}{\partial t^2} \qquad (h_1 < x < h_2)$$

For solving these equations the following boundary conditions are added.

For $x = 0$ $\qquad \theta_1 = 0 \qquad$ where $\theta_1 = \frac{\partial y_1}{\partial x}$

$y_1 = 0$

For $x = h_1$ $\qquad \frac{\partial^2 y_1}{\partial x^2} = 0$

$y_1 = y_2$

$\theta_2 = 0 \qquad$ where $\theta_2 = \frac{\partial y_2}{\partial x}$

$$\frac{\partial}{\partial x}\left(EI\,\frac{\partial^2 y_2}{\partial x^2}\right) - \frac{\partial}{\partial x}\left(EI\,\frac{\partial^2 y_1}{\partial x^2}\right) = m_1\,\frac{\partial^2 y}{\partial t^2} + Ky$$

For $x = h_2$

$$\frac{\partial}{\partial x}\left(EI\,\frac{\partial^2 y_2}{\partial x^2}\right) = m_2\,\frac{\partial^2 y'}{\partial t^2} = m_2\,\frac{\partial^2}{\partial t^2}\left[y_2(h_2) + h'\,\theta_2(h_2)\right]$$

$$EI\,\frac{\partial^2 y_2}{\partial x^2} = M(h_2) = h'\,m_2\,\frac{\partial^2}{\partial t^2}\left[y_2(h_2) + h'\,\theta_2(h_2)\right]$$

The integration of these equations was carried out by the method of MYKLESTAD. This method computes the bending moments, shearing forces, angular deflections and displacements for a given vibration frequency. All boundary conditions except one are introduced; the fulfilment of the latter at the end of the computation means that the system is vibrating in one of its normal modes and therefore the computed values of moments, shears, angles and deflections are the appropiate for the corresponding natural frequency. Computation was carried out on an ER56 Standard Electric Lorenz Computer.

### 5.11 Spectrum Response Curve. Acceleration Spectrum.-

The carrying out of modal analysis requires a curve of spectrum response for the locality in reference. Unfortunately no instrumental records of the 1960 earthquake were available, so that this information was not obtained directly. However an indirect approach may be used to this problem. On the basis of the degree of damage or no damage suffered by various structures of the Huachipato Plant. J. Blume (1) has proposed an acceleration spectrum for 1 to 2 % of critical damping. This spectrum leads to values of the order of 1 g for periods of 0,6 seconds in a curve which increases continuously for higher frequencies.

The selection of a design spectrum in the present state of our knowledge must be based largely on engineering judgment taking into account the damping characteristics and possible plastic yielding of the structure, together with an adequate safety according to the importance of the structure. Undoubtedly the refractory lining compressed against the metallic shell will be an important damping factor. In addition, the resisting structure of the space frame is highly indeterminate and provides for the formation of many plastic hinges, which may absorb energy in the plastic range before the collapse of the structure. The anchor bolts are designed for stretching without interference with the concrete and may be removed and replaced if necessary. They provide a new important possibility of energy absorption in the plastic range. The acceleration spectrum finally adopted was given by the equation

$$\alpha = \frac{0,20}{T} \leqslant 0,40$$

ıere $\alpha$ represents the percentage of gravity and T the period of the tructure in seconds.

### 5.2 Static Analysis.-

For a static analysis a seismic coefficient of 025 was selected and the rocedure shown in Fig. 6 was called for.

The influence of the masses above the top of the furnace structure were valuated with a seismic coefficient of 050.

## ı.- Conclusions.-

A discussion of the design criteria used above shows that the selection f earthquake loads was largely a matter of engineering judgment. This clear-y shows the need for systematic research in these types of structures in rder to clarify the vibration behaviour. For the second blast furnace at uachipato, experiments for the determination of the damping and of the eriods of vibration are envisaged. Measurements of strains and temperatures t various sections of the structure are also planned in order to study the ehaviour of the structure.

It is somewhat surprising to find that the basic structural concepts in blast furnace design have changed very little, whereas increasing demands have been made on the efficiency and capacity in recent times. Unless the structural concepts are revised in terms of the continuously increasing functional requirements there is a danger that an already strained structural solution may become inadequate. This danger is particularly serious as far as the earthquake problem is concerned, which imposes additional structural requirements.

Finally it should be said that a correct earthquake resistant design cannot be limited to the mere determination of conventional earthquake forces, without regard to specific structural problems. A complete earthquake design must take into account not only the assignment of earthquake loads but also construction methods and careful appraisal of all details.

One should never lose sight of the fact that a secondary failure in any equipment may mean serious losses for the industry in terms of production.

## Acknowledgment.-

The programming and computations were carried out by Professor Arturo Arias and Mr. Luis Petit-Laurent of the University of Chile.

## References.-

1. Blume, J.A. "A Structural Dynamic Analysis of Steel Plant Structures"; Bulletin of the Seismological Society of America, Vol.53, N°2, February 1963.

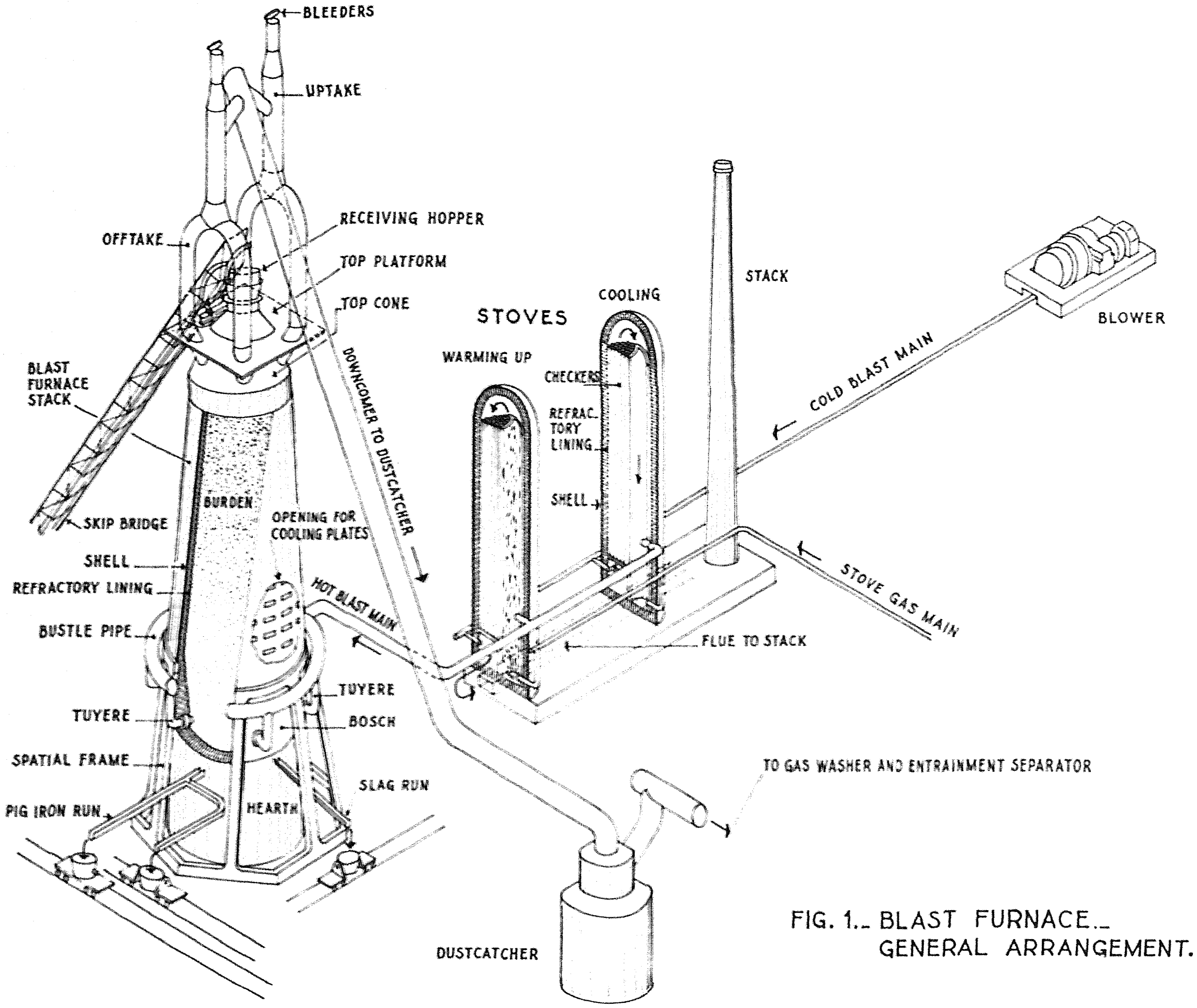

FIG. 1.– BLAST FURNACE.– GENERAL ARRANGEMENT.

REDUCIR A 10½" × 8¼"

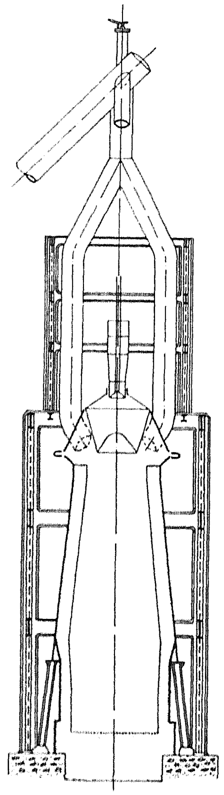

FIG. 2._ BLAST FURNACE - JAPANESE TYPE

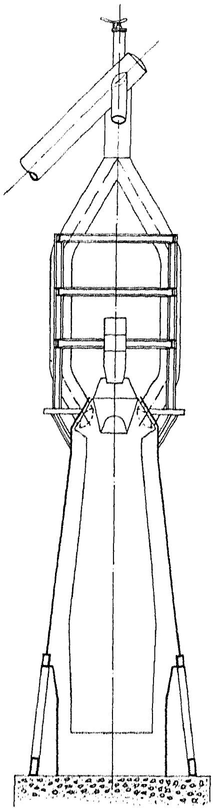

FIG. 3._ BLAST FURNACE - CHILEAN TYPE

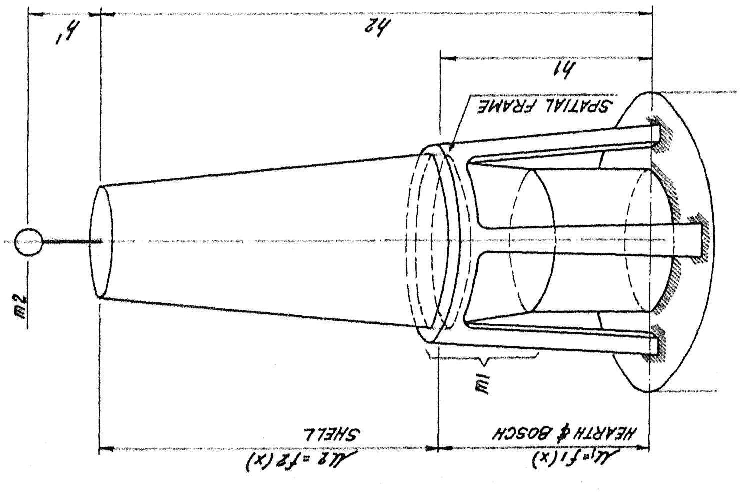

FIGURE 4.- SIMPLIFIED STRUCTURE

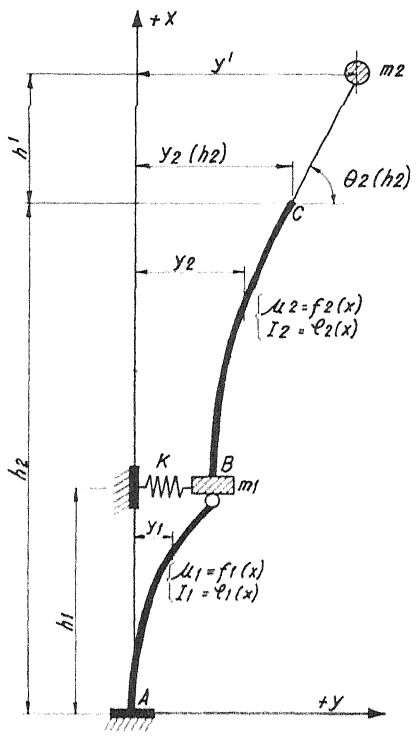

FIGURE 5.- STRUCTURAL DIAGRAM

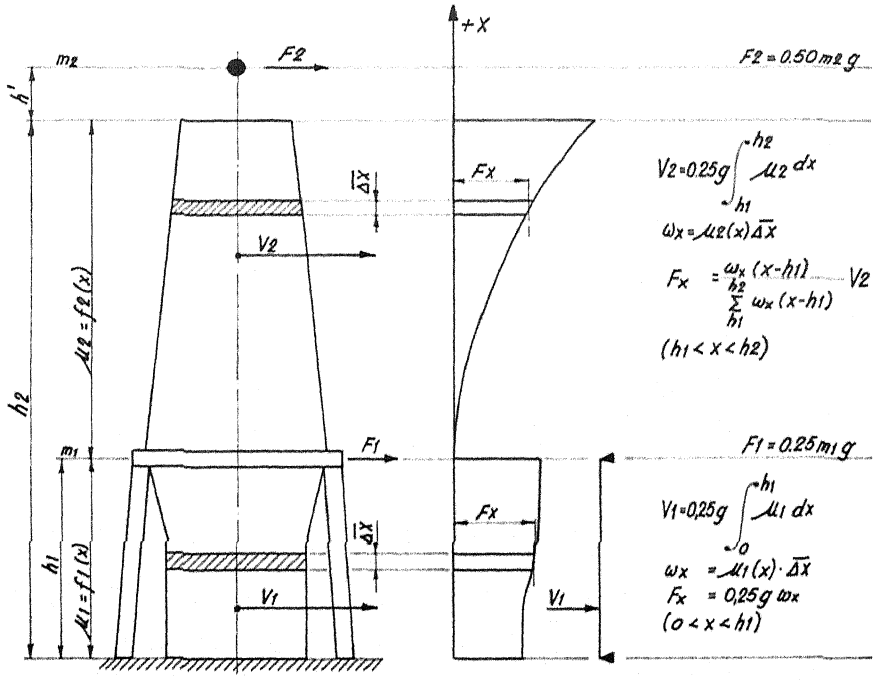

FIGURE 6.- STATIC ANALYSIS

## DESIGN PRINCIPLES OF EARTHQUAKE RESISTANT BLAST FURNACES

### BY R. FLORES

**QUESTION BY:** **J. RINNE - U.S.A.**

With low natural damping in such industrial type structures, has any consideration been given to providing damping devices?

**AUTHOR'S REPLY:** No damping devices have been provided. A comparatively large seismic coefficient has been used in the design to counteract the possible effect of a rather low damping. Additionally, we believe that the rubbing friction between lining and shell will provide a significant natural factor of damping.

**QUESTION BY:** **D.G. DOWNEY - NEW ZEALAND**

Reference to Fig. 5 shows the structure as being fixed at point A base. What was the foundation underlying material, on which the concrete foundation was placed?

**AUTHOR'S REPLY:** The foundation consists of a large reinforced concrete mat founded on a rather loose sand that has been previously preconsolidated by driving a certain number of 20' long pre-cast concrete piles.

**QUESTION BY:** **G. WOOD - UNITED KINGDOM**

It is encouraging to hear that the structure as shown withstood such severe earthquakes in Chile. Would the author state if the arrangements in the diagram showing a support for the blast furnace upstands was in fact incorporated in Blast furnace No. 1 or is that a new design feature in No. 2.

**AUTHOR'S REPLY:** The arrangement in which the top structure uptakes and top platform are supported in a ring incorporated to the shell immediately below the top cone, was not adopted in blast furnace No. 1. It was required in Blast Furnace No. 2 to resist the earthquake forces induced by a taller and heavier upper structure.