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# Seismic design practices of industries

E.Arze L.
*Pdt. Chilean Earthquake Engineering Society, Santiago, Chile*

ABSTRACT: Seismic Design codes are developed for buildings and houses and, thereby, they are not applicable to industrial structures that are altogether different. Because of this reason design of industrial facilities in most countries is not regulated and is based in the engineers experience and specifications prepared for each project. Nevertheless, because of the great impact of industrial seismic losses in the economy, there is a trend to incorporate these facilities in the codes. Chile, probably the most active seismic country in the world, has developed, since 1940, design practices for industries that have been particularly successful. The Chilean experience is compared with other 3 countries and recommendations for design methodology, specifications and code writings are submitted.

## 1 INTRODUCTION

Historically, seismic codes were first developed for buildings and houses, because it is there where most lives are lost. Once the goal of life protection was achieved, earthquake engineering turned its attention to the impact of seismic losses in the economy, which is specially significant in industries, as investments are usually high and lost production is most important. Thereby, seismic codes for industries, that are altogether different than for buildings, are relative latecomers in engineering.

The economic impact of seismic disasters in the development of the affected area has seldom been analyzed. In 1991, in a symposium organized by the UN within its program of the Decade on the Mitigation of the effects of natural disasters, Arze quoted the following figures proposed by several researcher for Chile:

| Seismic cost as % of GNP | |
|---|---|
| Direct cost of damages: | 2.9% |
| Lost production and other indirect costs: | 1.7% |
| Prevention: | 0.3% |
| Total seismic cost: | 4.9% |

The quoted figure is a tremendous burden when compared with the country GNP growth, that has ranged between 5% and 8%. It can be stated that earthquakes are largely responsible for Chile not being a fully developed nation.

The industrial seismic experience of 4 countries, Chile, the USA, New Zealand and the URSS is summarized below.

Chile is probably the most intense seismic country of the world. In its 450 years history it has been struck by 33 major destructive earthquakes, one every 7.1 years in this century, a frequency much higher than in Japan, California, Mexico or other seismic areas. On May 22, 1960, a 9.5 Richter earthquake, the largest ever recorded in world history, struck southern Chile. There were many industries in the epicentral area, including 2 Paper and 1 Pulp Mill, a Steel Plant, an Oil Refinery and 3 Sugar Plants. Damages were small, less than 0.5% of investments, and shutdowns ranged from none to a few days. In the opinion of the American Engineer John A. Blume, these plants suffered the worst known seismic exposure of any industrial facility to date. After 1960, Chilean industries, including 8 Pulp and Paper Mills up to 900 ADTD, have been equally successful in 4 more destructive earthquakes, Magnitudes 7.5 to 7.9. Only in 1989 the National Seismic Code NCh. 433 incorporated a chapter for industrial structures and facilities, based in the quoted experience of 50 years.

In the west coast of the USA, design practice and research of many years gave origin to the Seismic Design Recommendations, published in 1988 by the Structural Engineers Association of California (SEAOC) under the title "Non Building Structures"; these recommendations were incorporated, in the same year version of the Uniform Building Code UBC. Reported damages to industries in the M8.4 Alaska earthquake of 1964, and the recent M7.1 Loma Prieta earthquake of 1989 in California, were minor but slightly worse than in Chile. There were no collapses and only short shutdowns in major industries, but light industries in the epicentral region suffered significantly, and in most cases suspended production.

New Zealand Building Code, one of the world's most advanced, is not applicable to industries. To overcome the deficiency, the Ministry of Public Works published in 1981 recommendations for the Seismic Design of Petrochemicals Plants, that engineers use in others industries as well. The M6.3, 1987, Edgecumbe earthquake was the last to affect New Zealand. In spite of its low magnitude, damages at the 1300 T/D Tasman Pulp and Paper Co. Plant, located at Kawerau, 14 Km. from the epicenter, were extensive and serious. Cost of repairs was reported at US$ 85 million and shutdowns in some important units lasted several months. Because the plant was built between 1955 and 1975, before applicable seismic codes existed, most of the damage occurred in facilities not engineered or deficiently engineered to resist earthquakes. It is noted that damages affected mainly equipments, not structures. New Zealand engineers, whose seismic experience and know-how is internationally recognized, reported that very seldom they are allowed by the owners or suppliers to participate in the design of equipments. Perhaps this is the main reason for the failures at that mill.

The URSS Standard Regulations for Construction has specific requirements for industries that, according to Russian Engineers, are oriented in modern technical principles. Nevertheless the M7.0 Armenia earthquake of 1988 consequences on industries were, in the opinion of the joint American-Russian Reconnaissance team, disastrous. Authorities estimated that 85% of modern engineered structures in the strongly shaken region were destroyed. Many, if not most, industrial structures collapsed and at least 130 factories suffered long term interruptions. It has not been reported if there were any Pulp and Paper Plants among them. Apparently, failures were mainly due to deficient construction and lack of adequate inspection.

A summary of the quoted experience in 6 earthquakes is given below.

| Event | Mag. Richt. | Accel. | Damages to industries |
|---|---|---|---|
| Chile 1960 | M 9.5 | - | Minor |
| Chile 1985 | M 7.9 | 0.67 g | Minor |
| USA 1964 | M 8.4 | - | Moderate |
| USA 1989 | M 7.1 | 0.38 g | Moderate |
| URSS 1987 | M 6.3 | 0.25 g | Extensive |
| N.Zealand '88 | M 7.0 | 0.21 g | Extensive |

## 2 SEISMIC DESIGN METHODOLOGY

A large industry has a great variety of structures and equipments, many of them designed in other countries, by the suppliers, often mechanical engineers with no seismic experience. Additionally, the ease of emergency inspection and repair has to be always considered. Because of these unique features, an adequate methodology of work and coordination systems between the seismic specialists, the plant designers, the operators and the suppliers must be established.

In Chile, after many years in which problems have not been absent, the methodology described below has proved successful. Delays, claims, bad will and lack of cooperation have thus been avoided.

Generally speaking, vendors and suppliers have a good attitude towards modifying their equipment design for seismic reliability, as long as clear specifications are made available to them timely, during the bidding stage. Usually, they will modify their design at no extra costs.

### 2.1 Preliminary studies and coordination

The seismic factor must be considered since the initial phases of project organization.

- An early study of the site geology and seismicity is required. Investigate seismic risk, including tidal waves for coastal locations, and select the design earthquake considering the plant life (most codes use a 50 years event with 10% probability of excedence); locate active faults that, if too close, may require relocation of the plant.

- Proceed with soils investigations as soon as a location is decided. Special attention should be given to liquefaction of granular soils and dynamic settlement of loose sands and silts, that may produce extremely dangerous seismic settlements.

- Select the equipment that may be earthquake critical and prepare recommendations for the designers, owners and suppliers. Meetings may be advisable at this stage.

- Establish procedures for seismic design, review and approval, considering the experience of potential suppliers.

2.2 Complete Seismic and Structural Design Specifications for designers and suppliers should be prepared before actual design and procurement starts. This document should be included in the quotation requests and be a mandatory appendix of the contracts. If suppliers do not have earthquake experience it is convenient to prepare "Technical

Instructions to Suppliers" with sample applications of the Specification.

Following matters must be included in the Specification:

- Seismic Design Philosophy.
- Related material and design codes.
- Methods of seismic analysis, that may be: a) Static, a simplified system that replaces the earthquake effects by sets of horizontal forces; b) Dynamic, in which a mathematical model of the structure is analyzed for the accelerations of the expected earthquakes represented by a "Design Spectrum"; c) Historical, that applies to the model subjected to recordings of actual or artificial earthquakes. The Static Method can be used by structural engineers with little seismic experience, but its applications are limited. The Dynamic and Historical Methods are general, but require increasingly sophisticated software and must be used by experienced specialists.

- Design parameters such as seismic zone, ground acceleration, soils coefficients, load combinations, allowable deformations, etc.

## 2.3 Seismic Classification

All seismic codes classify the structure in accordance with their importance and risk involved in a failure. Each Class has an importance coefficient ("I") applicable to the seismic forces.

The Chilean Classification shown below coincides fairly well with the American and New Zealander.

- Class A. I = 1.25 Essential Facilities. A failure results in long shutdowns and serious production losses. It also includes facilities that must remain operative during the emergency. Typical of this class are, for instance, the Blast Furnace and the Fire Station of a Steel Mill.

- Class B. I = 1.25 Hazardous. A seismic failure involves risk of explosion, fire, poisoning, burning and similar. Typical examples are high pressure steam or chlorine piping, flammable fuel storage, etc.

- Class C. I = 1.0 Normal, not included in A or B, such as buildings, conveyors, ordinary piping, etc.

- Class D. I = 1.0 Minor, equipment and structures in which seismic forces are not critical but that, in case of failure, may produce costly shutdowns. Typical of this class are pumps, small motors and process vessels, etc.

The seismic engineer, jointly with the process engineers and the operators, must prepare complete lists of all the plant structures, equipments and facilities, with indication of the class, method of analysis, main parameters and other relevant information for each item. A sample sheet for a typical Pulp and Paper Mill is shown below.

SEISMIC CLASSIFICATION LIST
PROJECT: XYZ PULP AND PAPER MILL

| FACILITY N° | DESCRIPTION | CLASS | ANALYSIS | PARAMETERS | | |
|---|---|---|---|---|---|---|
| | | | | CLASS I | STRUCT. R | SOILS S |
| 100 | DRUMS | | | | | |
| 101 | Debarker | C | Static | 1.25 | 5 | 1.2 |
| 110 | Kiln | A | Static | 1.0 | 5 | 1.2 |
| 300 | CONVEYORS | C | Static | 1.0 | 4 | 1.2 |
| 500 | BUILDING | | | | | |
| 503 | Digester | A | Dynamic | 1.25 | 6 | 1.2 |
| 517 | Chemical Prep. | A | Static | 1.25 | 6 | 1.0 |
| 559 | Hospital, Fire Station | B | Static | 1.25 | 10 | 1.0 |
| 572 | Mill | C | Static | 1.0 | 6 | 1.0 |
| 594 | Office and Similar | C | Static | 1.0 | 10 | 1.0 |
| 600 | TANK FARMS | | | | | |
| 620 | Chemicals and Oil | B | Static | 1.25 | - | 1.2 |
| 643 | Others | C | Static | 1.0 | - | 1.2 |

## 2.4 Seismic review and approval

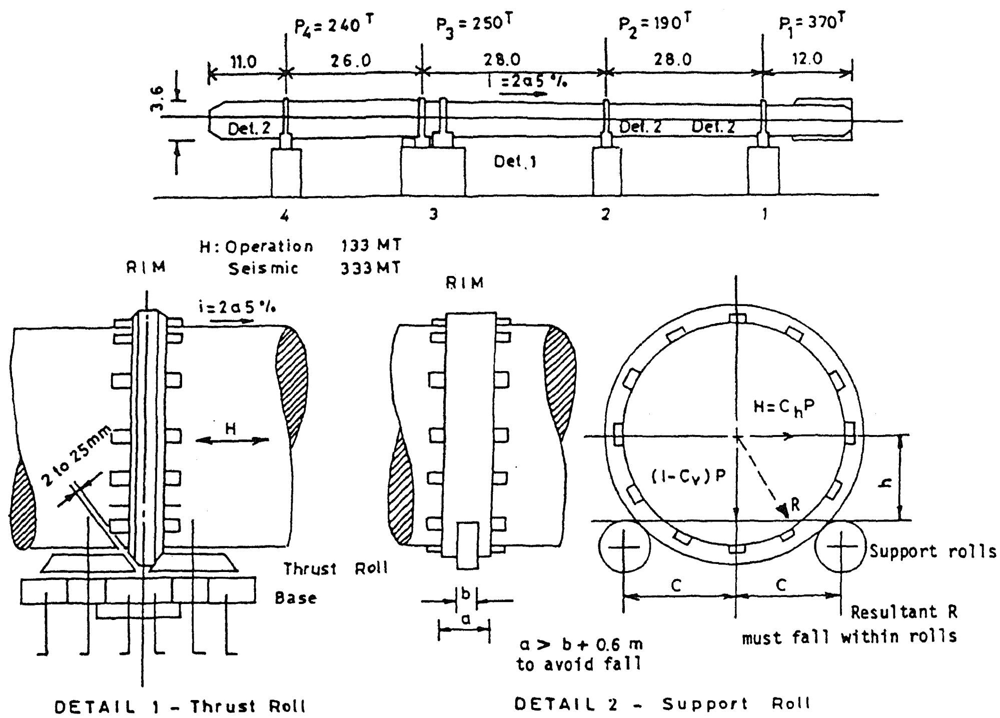
Experience in all seismic areas indicate that more than 85% of important failures are due to gross errors of construction or design concept. Modern codes, thereby, require mandatory and independent design review and construction inspection. Accordingly, all drawings computations and inspection reports must be submitted to the seismic reviewers, no matter how irrelevant they may seem.

Seismic review is done by steps, depending on the class.

Classes A and B: Step 1, Concept. Drawing showing the structural layout, weights and centers of gravity are submitted. At this stage it is often useful to schedule meetings with suppliers to agree in concepts and methods.

To illustrate the point, the following figure shows a limestone kiln that is typical in the cement, pulp, steel and other industries.

ROTARY KILN




In this case, because of the large heat expansions, all the longitudinal seismic force must be resisted at support N° 3. Special thrust rolls, with a capacity 2.5 times the standard in non seismic areas were required. If this fact is not detected at the early stages of the quotations and purchase negotiations it is almost certain that delays, claim and loss of good will will follow.

If meetings are not required, approval of Step 1 may take 1 week.

Step 2, Design. Once the concept is approved, design is completed using the Static Method and drawings and computations are submitted. Time required for review of a main unit is approximately 2 weeks. When no Dynamic Analysis is specified the review ends here.

Step 3, Dynamic Analysis. If the supplier engineer has previous experience, he may do the Dynamic Analysis incorporating the changes of Step 2 and submits it, with indication of programs, models, inputs, listings and results. Review may take 2 to 3 weeks.

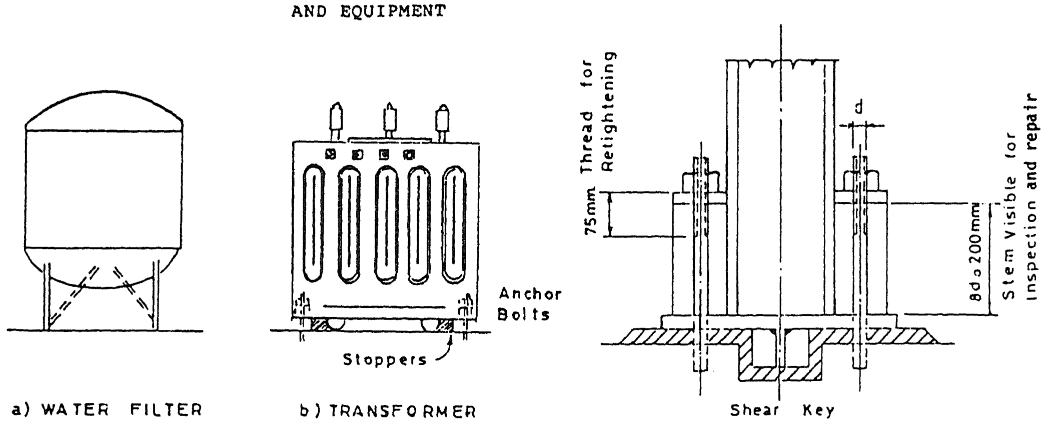
If the designer is not experienced, it is better to have the analysis made by the reviewer, who indicates the changes to the supplier. Time required is 2 weeks.

It is noted that Dynamic Analysis normally does not result in important changes nor an increase in structural weights. Fabrication may safely commence after Step 2.

Class C. The procedure is the same, but Steps 1 and 2 may be simultaneous and meetings are not normally required.

Class D. The figure below shows typical failures of minor equipment that, even if not important in themselves, may be responsible for costly shutdowns of more important units.

MINOR STRUCTURES
AND EQUIPMENT




a) WATER FILTER ADD BRACING

b) TRANSFORMER ADD STOPPERS AND ANCHOR BOLTS

c) SEISMIC COLUMN BASE

Fig. 7a. is a small vessel, normally supplied without bracing and 7b. a transformer, that in non seismic areas is mounted on wheels. Bracing and adequate anchorage can be easily supplied. In Class D equipment supplieres are requested to submit drawings with indication of weights, centers of gravity, dimensions and anchoring details. Review requires 1 to 2 days.

Fig. 7c. shows the recommended detail of a seismic column base. Anchor bolts shafts are exposed for ease of inspection and repairs.

## 3 CONCLUSIONS AND RECOMMENDATIONS

3.1 Industries can be safely and economically designed to resist earthquakes with minimum losses and shutdowns.

A good seismic design does not necessarily carry an associated important additional investment cost of the plant equipment, civil works and other installations.

3.2 The earthquake factor should be considered since the early stages of project planning.

3.3 Mandatory Seismic Design Specifications and coordination systems of design, review and approval must be established before design and procuring are initiated.

3.4 Seismic design should contemplate the ease of inspection and repairs in addition to the protection of life and property.

3.5 Procedures for shutdown, inspection and repairs during and after the emergency must be incorporated in the Operation Manuals and plant personnel trained and drilled in them.

3.6 Adequate earthquake insurance considering the seismic design done must be carefully negotiated.

3.7 Because of the large impact on the economy due mainly to shutdowns and loss productions, country should incorporate seismic requirements for industrial facilities in their Codes.

## REFERENCES

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