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DESIGN OF BOILER MEMBRANE WALL SUPPORT FOR LARGE EARTHQUAKE ACTIONS

P. Poppelka(1), E. F. Cruz(2), Ľ. Gavura(3)

Abstract

The submission contains a presentation of theoretical analyses and practical application of the results to the design of membrane (water wall) skeleton for two steam boilers installed in a highly active seismic region of Chile.

Boiler membrane skeleton was one of the most difficult problems, which was necessary to solve during designing of the boilers. It was caused due to the impossibility to change design dimensions related to the technological process for steam production with required parameters, large dimensions of each membrane panel, important operation loads, but mainly due to strong interaction between the membrane skeleton and other parts of the steel support structure, due to which the dynamic response has a large influence on its operation and emergency loads. The computation of the seismic loads for membrane skeleton was performed using a sequence of analyses, but with interaction of surrounding construction. The membrane skeleton was solved together with buckstay system, dynamic behaviour of internal tube systems and with connection to steel structure through spring hanger elements and the guiding system.

The theoretical and detail design of special highly ductile elements in the guiding system is the most significant part of membrane skeleton design solution.

Keywords: membrane wall, ductile element, guiding system

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(1) *Head of Technical and Design Analyses Dept., SES a.s. Tlmače, Slovakia, peter_poppelka@ses.sk*
(2) *Senior Seismic Specialist, EQCO Earthquake Engineering Consultants, ecruz@eqcoeng.com*
(3) *Designer, SES a.s. Tlmače, Slovakia, lubos_gavura@ses.sk*

Introduction

In the mid of 2012 two dry-bottom boilers of very similar designs (Colbún, Bocamina), each of 370MWe output, were put into operating in the region Offshore Bio-Bio in a Chilean city Coronel. Both boilers were designed and manufactured by Slovenské energetické strojárne, a.s., the company in Slovakia. Although, both boilers are involved in covering the total energy consumption of Chile, yet from the point of view of installed power capacity, the basic concept of the pressure system and/or set process parameters, the plants are not anything extraordinary. During its 65-year activity in the market the producer has gained rich experience in deliveries of plants of substantially higher capacities. Nevertheless, the phase of designing work was a great challenge for the producer in both contracts as there were very strict requirements of the client for reliability in operation, safety and increased resistance of the entire plant to high-intensity earthquake. Handing over the work into operation and its connecting to the energy supply network of Chile was conditioned by issuing a certificate by Earthquake Engineering Consultants the authorized company approving in accordance with applicable Chilean legislation all the designs and detailed solution of selected construction nodes based on submitted results /reports of special dynamic and stress analyses.

Fig. 1 – View of a Colbún power station

Surrounding area of Coronel is a very active seismic area. On May 22, 1960 Lumaco, the city approximately 125km south of Coronel recorded the strongest earthquake, Richter magnitude scale M=9.5. The contract required to envisage for Colbún boiler a possibility of earthquake of Richter magnitude scale M=8.0÷8.5 in the distance of 50 km from the site that corresponded to the calculation value of PGA=0.46g [1].

Membrane skeleton of the boiler

Solving the seismic design of Colbún boiler the most problematic construction unit was the membrane skeleton of the boiler. The skeleton is formed by a thin-walled orthotropic shell, i.e. combination of tubes of the pressure system of the evaporator and the wall superheater with thin fins. The tubes and fins create a welded gas-tight cover of the combustion chamber of the boiler and the space filled with convection heat-exchanging surfaces. The membrane skeleton is also a supporting system interacting with a lot of other construction units/components of the entire boiler. To sustain pressure effect of flue gas and to ensure shape stability, the membrane skeleton is reinforced by a system of buckstays. The sketch of the solved membrane skeleton is shown in Fig. 2.

The membrane skeleton is hung in its top part onto the supporting structure through flexible suspension and to limit horizontal movements it is connected at several levels to the supporting structure by a system of guiding.

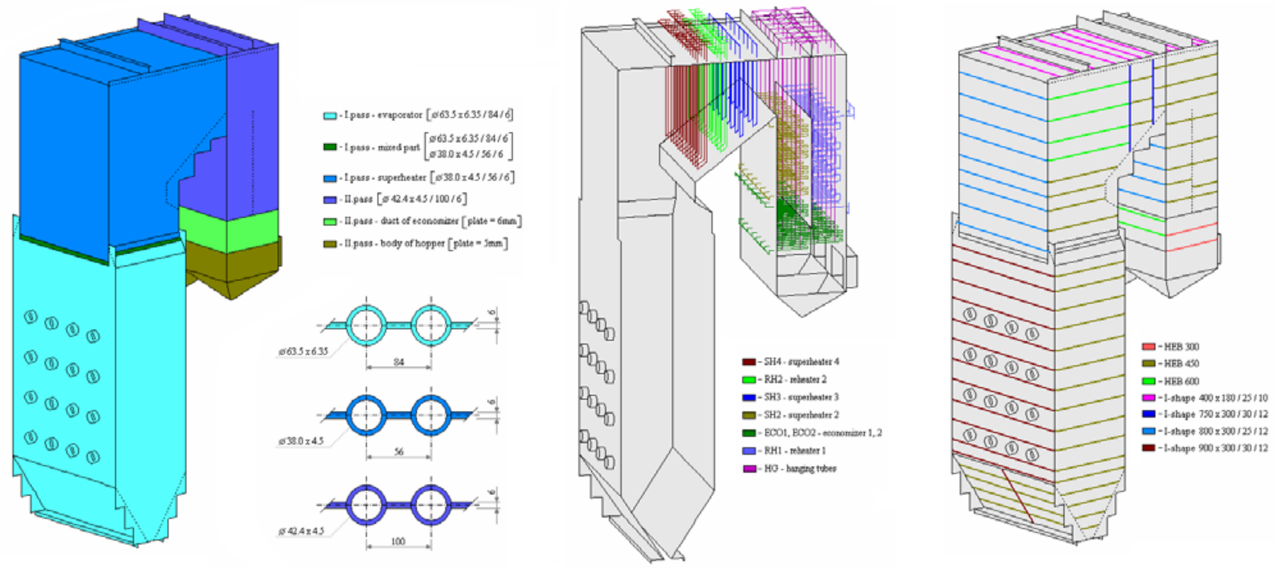


Fig. 2 – Boiler membrane structure with buckstays and convection heating tubes

In the design of the membrane skeleton it was necessary to take into account that its dimensions are practically unchangeable as they are given by the process requirements to ensure the required output/parameters of the boiler. Increasing the load-bearing capacity of the membrane skeleton by additional reinforcement is problematic and limited considerably due to problems resulting from various heating and various thermal expansions of the membrane skeleton and components attached to it.

The membrane skeleton of the boiler along with internal heating surfaces, the buckstay system, insulation and steel sheathing make up an important dynamic mass. The total weight of the complex is approximately 3880 tons. In case of oscillation within a wide spectrum of shapes the occurring dynamic loads depend on correct simulation of real rigidity of the membrane skeleton for interaction with the supporting structure as well as for interaction with internal heating surfaces. As the membrane skeleton is an orthotropic shell, the required rigidity parameters have been specified by means of special equivalent geometry [2].

The stress of the membrane skeleton is influenced substantially by hitting of oscillated tubes of internal heating surfaces. During seismic excitation just several tubes near the particular membrane panel come into mutual interaction among themselves or into interaction with the membrane skeleton where the hitting tubes transfer gained kinetic energy. The other tubes of the bundle oscillate freely due to widening gaps between the individual tube panels oscillating in phase. This problem was solved in details in [3]. It must be noted that the original requirement of the client concerning guiding the internal heating surfaces in two orthogonal horizontal directions was not accepted because increasing their rigidity resulted just in substantial increase of dynamic loading of the membrane skeleton and that was contrary to the relevant contract requirements.

The required resistance of the membrane skeleton to dynamic effects of hitting of the internal heating surfaces was achieved by suitable modification of the classical buckstay system with detailed revision of required load-bearing capacity of the points of interaction of buckstay elements with tubes of individual membrane walls [4].

Guiding system

To secure the position of the membrane skeleton of the boiler against wind load effects, flue gas pressure effects and thermal expansion movements when the boiler is heated / cooled down, it was necessary to solve it by a system of horizontal guiding of various types at several elevations according to Fig. 3.

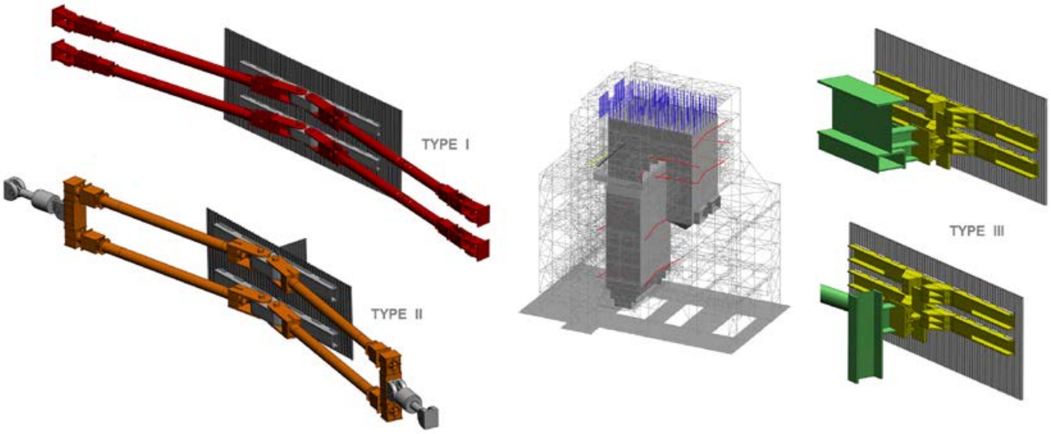


Fig. 3 – Guiding system of the bolier

The guiding system is very sophisticated. Its design envisages all spatial movements of the membrane skeleton using freer tolerances at pin joints in guiding of the combustion chamber of the boiler or adding shock-absorbers to compensate stronger thermal expansion movements of the 2nd pass of the boiler, which could not be solved by the freer tolerances.

Calculation of dynamic loading

The serious issue in sizing the boiler guiding components occurred while solving the interaction of the membrane skeleton with the supporting structure during application of seismic excitation. There was used an extensive calculation model for this calculation containing detailed simulation of the supporting structure, the boiler with accessories, additional parts of boiler, concrete base plate and elements simulating flexible features of the soil.

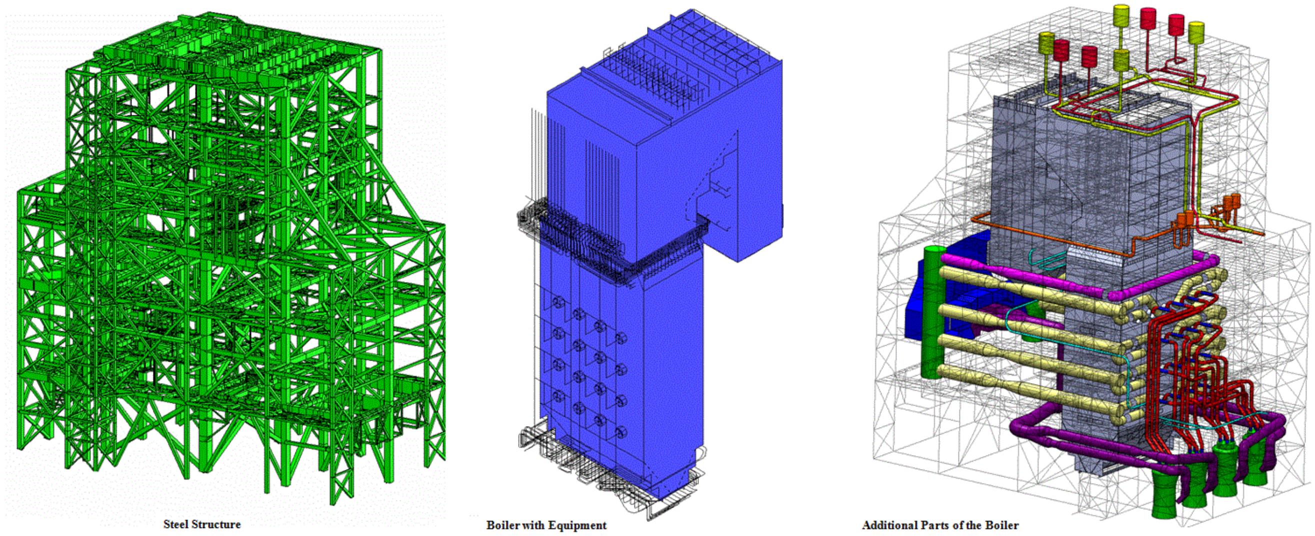

Steel Structure **Boiler with Equipment** **Additional Parts of the Boiler**

Fig. 4 – Selected parts of the dynamic model of the facility

The calculation of dynamic loading in boiler guiding components was done by design spectrum for elastic analysis with response modification factor R=3.0 and modal damping 3%.

Table 1 – Important parameters of the mathematical model

total oscillating mass	45 360 tons	total effective mass	92.6% ÷ 96.6%
number of own shapes	800	range of natural frequencies	0.16Hz ÷ 8.78Hz

In spite of several modifications of the boiler guiding system the resulting dynamic loading, i.e. horizontal force in guiding ranged from 2000 to 2500kN at some levels. Although the guiding structure elements are designed to fulfil the conditions of rigidity and stable resistance even to such an extreme loading, the weakest link of the entire system seems to be the membrane skeleton parts, which the relevant boiler guiding elements are connected to and whose required solidity and reliability in extreme operating conditions cannot be ensured by common technical means.

The seismic reviewer in charge helped to solve this almost desperate situation and suggested to limit seismic loading in each locality of guiding to a value that the membrane walls are feasibly able to transfer and so to be protected against earthquake effects while fulfilling the requirements of boiler guiding under normal operating conditions. Practically, it meant to install ductile elements in the guiding system specially designed for each individual horizontal guiding of the boiler.

Design of ductile elements

In the design of ductile elements it was used non-linear characteristics of generally known tensile diagram of ductile materials. Having exceeded the yield point of membrane stresses of test specimen, there is fast increase of plastic deformations with minimum increase of loading necessary for their development. Solution of the whole problem was based on this principle. The guiding system of the boiler integrated the ductile boxes with adjusted dimensions and localities, which act as natural limiter of size of loading. Instead of draw bars typical for specimens used for tensile tests, in the boxes there are used sheet segments designed as “beams” of identical stress in each its cross-section.

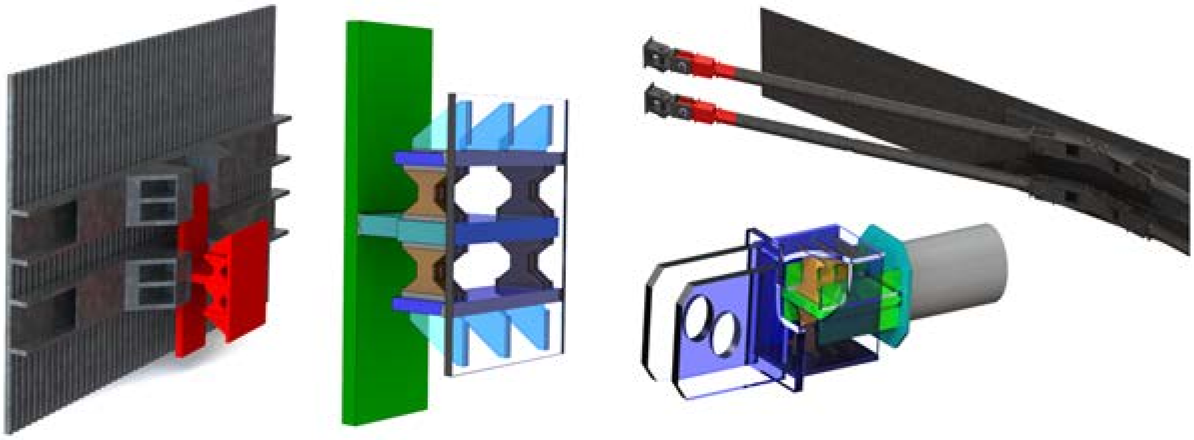
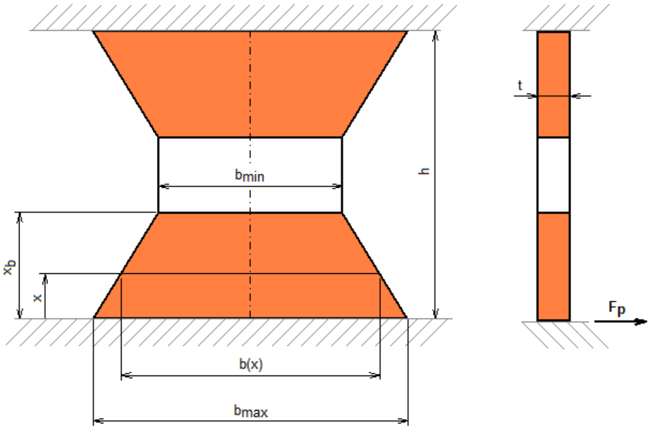


Fig. 5 Examples of ductile elements in different localities

Shaped plate made of ductile material is a basic design element of all the ductile boxes. Unless material reinforcement is considered after exceeding the yield point, then the force F_p required for total plasticizing of marked volume of the material, Fig.6, can be determined sufficiently precise according to the Eq. (1) and relative displacement Δ of fixed edges of the shaped plate according to the Eq. (2). The minimum width of the plate to transfer the shear force F_p safely is given according to the Eq. (3).



$$F_p = S_y \times \frac{b_{max} \times t^2}{2 \times h} \tag{1}$$

$$\Delta = \varepsilon_{max} \times \frac{2 \times h \times x_b}{t} \cdot \left(1 + \frac{b_{min}}{b_{max}}\right) \tag{2}$$

$$x_b = \left(0.5 - \frac{F_p}{0.7 \times S_y \times b_{max} \times t}\right) \times h \tag{3}$$

Fig. 6 – Calculation sketch of shape plates

The material of shaped plates in the Eq. (1) ÷ Eq. (3) is represented by the yield point S_y and the maximum permissible value of plastic strain ε_{max}. To set any required value of the limit force loading for the relevant ductile box and hence for the relevant locality of the membrane skeleton, there are three geometric parameters available, b_{max}, t, h and certainly an appropriate number of shaped plates arranged in parallel.

Conclusions

The way of protection of the membrane skeleton of the boiler by limitation of the maximum permissible loading by means of designed ductile elements is a very simple, effective and inexpensive as well as technically elegant solution of the problem. In spite of the fact that Eq. (1) ÷ Eq. (3) resulted from application of simplified mathematical apparatus and that a certain deviation from the exact solution occurs due to variation of material features, design details and particular manufacturing conditions, with regard to reserves applied at the side of acting seismic loading the solution can be viewed as reliable and satisfactory for further practical applications in plants of the similar character.

The design of ductile elements was just one of several interesting solutions required to ensure seismic resistance and reliability of the entire project. It is necessary to emphasize that during assembly activities in 2010 the boiler Colbún was “audited“ by a very strong earthquake (Maule Earthquake of 27 February 2010, Mw=8.8) with no impact on its construction and with possibility to continue with the assembly phase without any restrictions and time loss.

Acknowledgements

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