SEISMIC ACTION INFLUENCE ON THE PRESSURE PARTS OF THE WATERTUBE STEAM BOILER CONSTRUCTION

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Abstract: *The main aim of this paper is to analyze seismic action influence on the pressure parts of the watertube steam boiler construction. Design of the structures in earthquake areas according to Eurocode 8 (EN 1998-1) has been explained and performed on pressure parts construction of one watertube steam boiler. Using the finite element method, reaction forces in the supports, which occur under the influence of boiler weight and during the earthquake in the Abaqus / CAE 2016., have been calculated. At the end, the comparison of the results is shown and analysis of the results is given. Comparison of the European standard EN 1998-1: Design of structures for earthquake resistance and Turkish TEC-07: Turkish Earthquake Code in analysis of the watertube steam boiler is also done, in order to determine whether structures analyzed by EN 1998-1 can also be built on the territory of Republic of Turkey.*

Keywords: STEAM BOILER, SEISMIC ACTION, EARTHQUAKE, FINITE ELEMENT METHOD, EUROPEAN, TURKISH, REGULATIONS

1. Introduction

A steam boiler or steam generator is the central part of any thermoenergetic power plant. Field of steam boilers constructioning has been developing for last 200 years and significant progress has been made over the last few decades. The principle of the thermoenergetic power plant operation can be described in a couple of simple steps: the working medium is heated to the point of evaporation - the generated steam drives the turbine and the turbine generates electricity. Although it seems simple at first glance, the gradual improvement and optimization of the process and plant performance in which the process takes place, has led to the point that creation and management of such a facility has becoming a sort of science. In technical terms, steam boiler is a complex steam generating system used for various purposes. It includes various heat transfer phases from flame to heating surfaces (economizer, drum, heat exchanger, superheater, air heater, etc.) as well as various auxiliary systems such as fuel delivery, water treatment, cleaning system, water and impurities drainage, flue gases ducts, etc[1,2,3]. Steam boilers can be divided by several different criteria and generaly they are classified into two categories: firetube and watertube steam boilers. Recently, watertube steam boilers have received great attention due to their benefits regarding costs, simplicity and safety of operation[4,5]. Ease of operation, safety, inspection, maintenance, repair, and cleaning should be of major concern when considering the design and arrangement of boilers[6]. Since the steam boilers operate at high temperature and high pressure conditions it is of great importance to make an effective assessment of their safety under abnormal situations. However, such facilities are subject to several operating failures and accidents, which could expose the system to technical problems and serious hazard[7,8]. Therefore, when conclusion about safe operation is needed to be done it is also important to take a seismic action into consideration too. The European standard EN 1998-1, Eurocode 8: Design of structures for earthquake resistance: General rules, seismic actions and rules for buildings[9] is used for calculations of buildings and engineering structures for location in Croatia where one watertube steam boiler it is itended to be built. Considering possibilities of building the same watertube steam boiler construction in Turkey, an analysis of differences and similarities between European and Turkish regulations in seismic analysis where Turkish Earthquake Code 2007, or TEC-07[10], Turkish standard used for calculations of structures has been done. Standard EN 1998-1 is used as a foundation in seismic analysis of the watertube steam boiler design. Influence of seismic actions on pressure parts of the watertube steam boiler construction is analysed by applying the design spectrum for elastic analysis on the watertube steam boiler construction model made in Abaqus CAE[11]. Later the same Abaqus model of the steam watertube boiler construction is analysed using the Turkish standard TEC-07. Obtained results for displacement and raction forces in boiler construction supports are compared. Earthquake is an endogenous process that occurs due to displacement of tectonic plates, and consequence is the shaking of Earth's crust and release of a large amount of energy[12]. Factors affecting the strength of earthquakes are the amount of released energy, the depth of the hypocentre, the distance of the epicenter and composition of the Earth's crust. According to EN 1998, the earthquake motion in specific point on the surface is represented by an elastic acceleration spectrum of base ground response that is called an elastic response spectrum. The shape of the elastic response spectrum is assumed to be the same for two levels of earthquake action in the case of a requirement for no destruction (limit state of load-carrying capacity) and for requirement of limited damage. Horizontal earthquake action is described by two orthogonal components, assumed to be independent, and represented by the same spectrum of response. When earthquakes affecting a location occur in different sources, consideration should be given to the possibility of using more than one form of spectrum in order to appropriately show the calculated earthquake effect. In such circumstances, for each type of spectrum and earthquake, different values of the calculation acceleration on the ground floor will typically be required. For important constructions, the effects of increase due to topographical circumstances should also be considered[8,13].

2. Finite element modeling

To help ensure comparability of the results given by analysis according to EN 1998-1 and TEC-07, it was necessary to undergo the watertube steam boiler construction similar conditions. Ground conditions, seismic zones and other conditions regarding the site of the structure by EN 1998-1 and TEC-07 were all provided by Đuro Đaković Termoenergetska postrojenja d.o.o. The boiler model is modeled according to the same documentation and associated loads, constraints and boundary conditions are assigned (Fig. 1). For finite element calculation, the finite element method was used, and the Abaqus/CAE 2016 program was used. The membrane walls of boiler is approximated by an equivalent orthotropic plate and it is discretized by a four-knode double-curved shell finite element. When calculating the reaction in the base supports of the steam boiler, the load of the weight of the boiler construction, working medium, dirt, walling and insulation is taken into account. Materials of membrane walls and bands belong to the group of low carbon steel $C \leq 0.3\%$ carbon. The calculation temperature is the water vapor saturation temperature. Assuming that the mechanical properties of the boiler construction are isotropic, the elasticity modulus for all three materials is approximately equal to 181990 MPa. For the Poisson factor, the value of 0.3 is adopted.

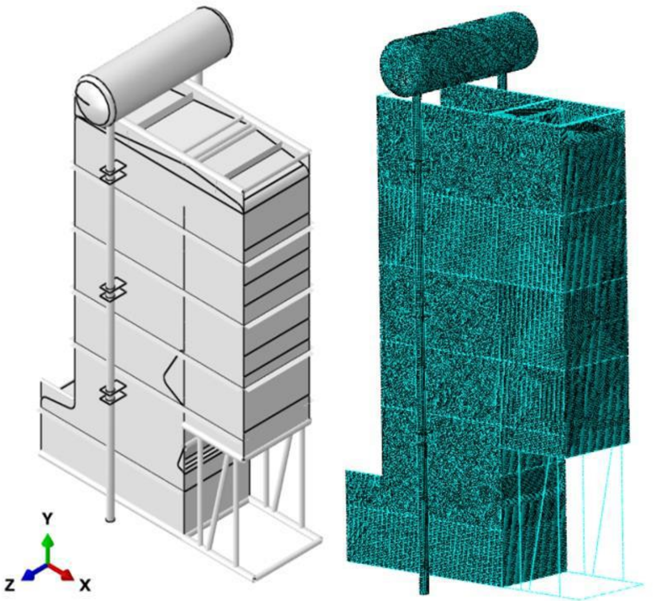
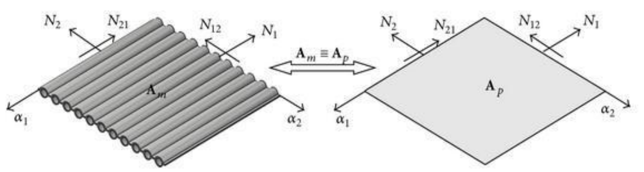
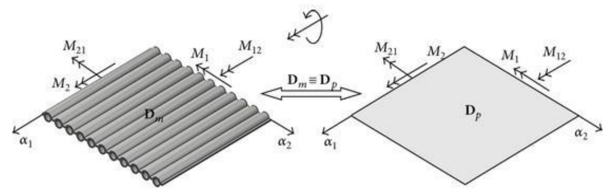


Fig. 1 *Geometry and meshed finite element model of watertube steam boiler*

The boiler is supported on ten supports, five on the left side wall distribution chamber and five on the right side wall chamber. The boiler's drum is supported on two downcommer's tubes. In the second passage of the boiler the packages of heating surfaces are set. Membrane walls of the boiler are made with a step of 80 mm. The cross section of the membrane tubes is 57×4.5 mm and a membrane strip thickness is 6 mm. Members of the elasticity matrix of equivalent orthotropic plates, for the membrane boiler walls, are calculated according to[14] and are: A11=2006179 N/mm, A12=12772 N/mm, A22=42573 N/mm, A33=432024 N/mm, D11=587686516 Nmm, D12=67884006 Nmm, D22=8435021 Nmm and D33=47343775 Nmm (Fig. 2).



a)



b)

Fig. 2 *a) Internal forces and membrane rigidity of the Am membrane equivalent to the internal forces and the membrane stiffness of the orthotropic plate Ap, b) Internal moments and flexural stiffness of the membrane wall Dm equivalent to the internal moments and the flexural stiffness of the orthotropic plate Dp*

Conditions by EN 1998-1

For steam watertube boiler analysed by EN 1998-1 standard, conditions were given as followed:

- Ground type C
- Peak ground acceleration $a_{gR} = 0.16g$
- Building importance class III (importance factor $\gamma_I = 1.2$)
- Behaviour factor $q = 1.5$

Peak ground acceleration a_{gR} is obtained from the seismic map of Republic of Croatia. Frequency analysis of the ABAQUS model showed vibration periods of the construction shown on Fig. 3 and Fig. 4.

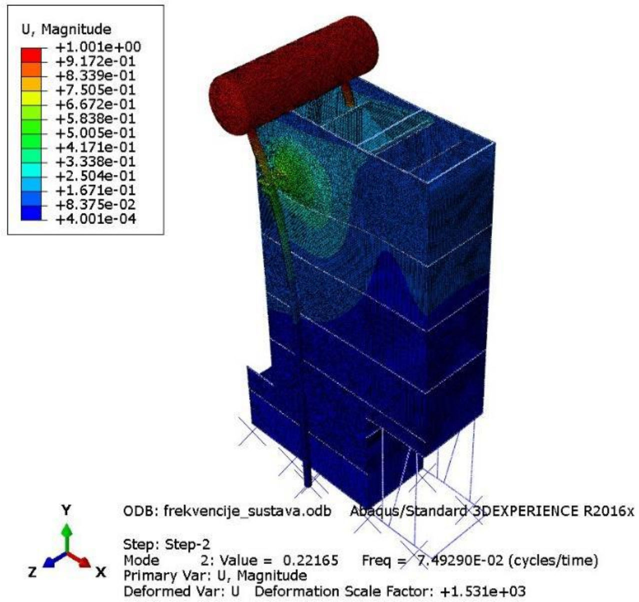


Fig 3. *First mode of vibration obtained using finite element analysis*

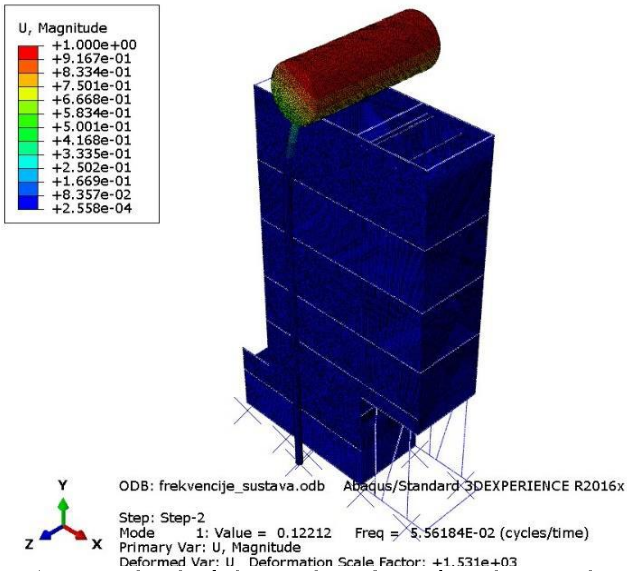


Fig 4. *Second mode of vibration obtained using finite element analysis*

In finite elements results frequencies are expressed in number of cycles in time and they are needed to be recalculated in Hz, beacuse loads of density is given in kg/mm^3 and in kg/mm^2 as wall load. Geometry is defined in mm and Young's modulus of elesticity is assigned in N/mm^2. In order to obtain frequency in Hz, frequency obtained in finite element analysis is multiplied by frequency coefficient k_f =31.62. This gives vibration periods:

- T = 0.57 s (for X-axis)
- T = 0.42 s (for Z-axis)

Considering the vibration periods, ground type and values of the parameters describing the recommended Type 1 elastic response spectra, EN 1998-1 recommends the following equation for calculating the design spectrum S_d (T) for elastic analysis:

$$S_d(T) = a_g \cdot S \cdot \frac{q}{1.5} \qquad (1)$$

where S represents the soil factor from the table of values of the parameters describing the recommended Type 1 elastic response spectra and a_g design ground acceleration on type A ground.

Conditions by TEC-07

Conditions used for analysis by TEC-07 are listed below:

- Group C soils, local site class Z3

- Seismic zone 3 (A_0 = 0.2)
- Building type 2 (importance factor I = 1.4)
- Structural system behaviour factor R = 4

Ground conditions and vibration periods determine the sequence of equations used for calculating the reduced acceleration spectrum ordinate. The territory of Republic of Turkey is divided into four seismic zones. Different effective ground acceleration coefficient is assigned to each zone.[15]

Since the same construction model is used for TEC-07 analysis, vibration periods of the construction are the same as the vibration periods for EN 1998-1 analysis. For previously listed conditions, TEC-07 provides following equations:

$$S(T) = 2.5 \quad (2)$$

where S (T) is the spectrum coefficient and

$$R_a(T) = R \quad (3)$$

where R_a (T) is the seismic load reduction factor.
Equation used for calculating the reduced acceleration spectrum ordinate S_{aR} (T) is:

$$S_{aR}(T) = \frac{S_{ae}(T)}{R_{ae}} \quad (4)$$

where $A(T)$ is the spectral acceleration coefficient determined by:

$$A(T) = A_0 \cdot I \cdot S(T) \quad (5)$$

Seismic load

After calculating both design spectrum for elastic analysis S_d (T) by EN 1998-1 and reduced acceleration spectrum ordinate S_{aR} (T) by TEC-07, significant difference is visible:

$$S_d(T) = 3.61 \text{ m/s}^2 \quad \text{(EN 1998-1)} \quad (6)$$

$$S_{aR}(T) = 1.7168 \text{ m/s}^2 \quad \text{(TEC-07)} \quad (7)$$

Seismic load is applied on the watertube boiler construction model in Abaqus, in both positive and negative directions of X and Z axis.

3. Results of analysis

For stability of the watertube boiler construction during the earthquake, support reactions in Y-axis direction are relevant. Reaction forces oriented in the negative direction of Y axis indicate instability of the steam watertube boiler construction during the earthquake. Fig. 5 shows the arrangement of supports of the steam watertube boiler construction and the direction of seismic load for X (MOD_X) and Z (MOD_Z) axis.

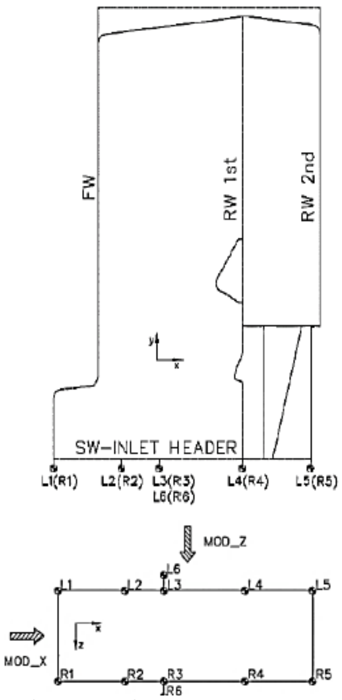


Fig. 5 *Arrangement of supports of the steam watertube boiler construction*

Table 1 and Table 2 show support reactions obtained in both EN 1998-1 and TEC-07 analysis as a result of gravitational and seismic load for X and Z axes. Since support reaction forces are the same for negative and positive direction of the seismic load, only forces in positive direction are presented. The same reaction forces for X and Z for TEC-07 are shown on Fig. 6 and Fig 7.

Table 1: *Support reactions in Y-axis direction for seismic load - X axis (MOD_X)*

Support	Support reaction MOD_X+ (EN 1998-1) F_Y /N	Support reaction MOD_X+ (TEC-07) F_Y /N
R1	-87 890	-23 473
R2	-199 533	-27 572
R3	99 078	141 235
R4	516 065	364 185
R5	417 854	289 242
R6	165 750	168 841
L1	-87 732	-23 400
L2	-199 183	-27 322
L3	99 703	141 507
L4	518 193	364 782
L5	417 902	289 107
L6	165 772	168 854

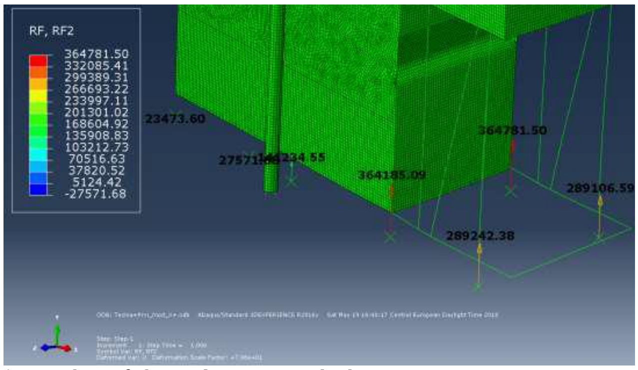


Fig. 6 *Values of obtained reactions in boiler construction supports using finite element analysis in Y direction for MOD_X (TEC-07)*

Table 2: *Support reactions in Y-axis direction for seismic load - Z axis (MOD_Z)*

Support	Support reaction MOD_Z+ (EN 1998-1) F_Y /N	Support reaction MOD_Z+ (TEC-07) F_Y /N
R1	308 451	165 013
R2	399 423	257 273
R3	480 905	322 819
R4	667 830	436 360
R5	443 718	301 543
R6	249 644	208 738
L1	-237 741	-94 740
L2	-141 240	0
L3	-122 695	-35 739
L4	-220 264	-13 595
L5	-95 398	-44 997
L6	93 349	-134 413

Distribution of displacements of finite element model of watertube boiler pressure parts construction for EN 1998-1 is shown on Fig. 8 and Fig. 9.

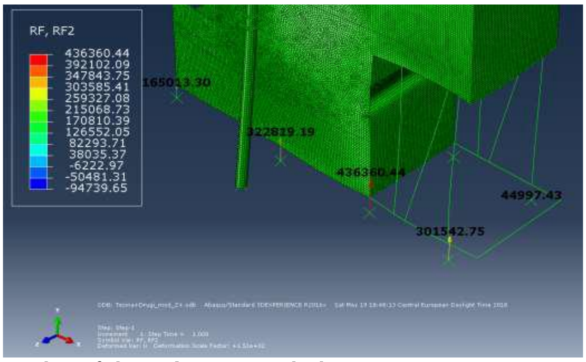


Fig. 7 Values of obtained reactions in boiler construction supports using finite element analysis in Y direction for MOD_Z (TEC-07)

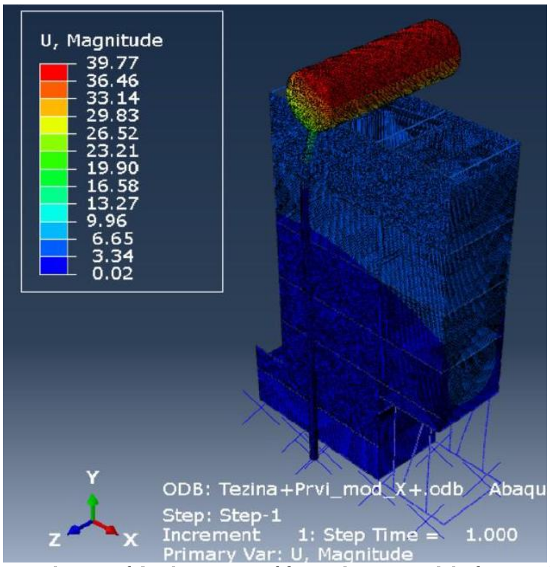


Fig. 8 *Distribution of displacements of finite element model of watertube boiler pressure parts construction for MOD_X (EN 1998-1)*

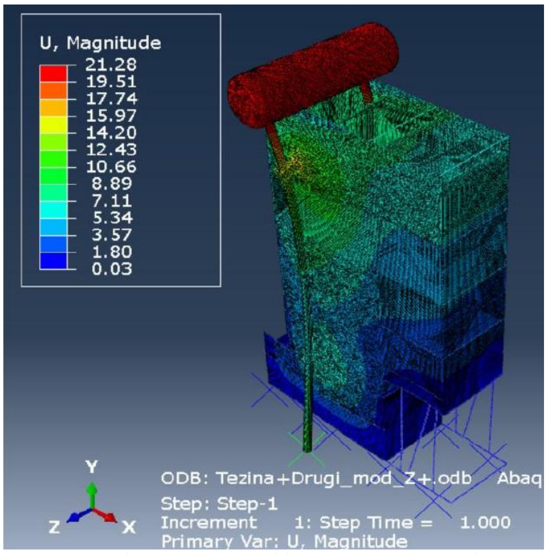


Fig. 9 *Distribution of displacements of finite element model of watertube boiler pressure parts construction for, MOD_Z (EN 1998-1)*

4. Conclusion

Partialy simplified and aproximated boiler geometry is modeled in the Abaqus/CAE 2016 softvare package. The system's own frequency was obtained by calculating the spectral acceleration, i.e., calculation spectrum during the occurance of earthquake. Further numerical calculations gave reaction values in boiler supports as well as deformation of boiler's system parts. Analysis of the steam watertube boiler construction model behaviour due to different seismic loads determined by EN 1998-1 and TEC-07 yielded visibly different results. Although, both analyses indicated instability of the steam watertube boiler construction in the same support locations. To assure comparability of analyses, the same model of the watertube steam boiler construction is analysed and only seismic load is changed based on TEC-07 calculation. Analysis by EN 1998-1 brought up much greater reaction forces unlike TEC-07. With that considered, it can be assumed that EN 1998-1 is more conservative than TEC-07 and that construction analysed by EN 1998-1 can be built in Republic of Turkey. It is necessary to emphasize that previous conclusion has significance only for analyses of support reactions of structures subjected to lateral seismic loads calculated by EN 1998-1 and TEC-07. For concrete buildings, reinforced concrete buildings, steel buildings, wooden buildings and masonry buildings, different and more complex analysis and comparison is needed. In this specific case the analysis of the results concluded that the reaction forces in the boiler supports during the occurance of the earthquake are adversely affected and that for this kind of boiler support there is a risk of overturning. In order to prevent the risk of overturning, it is necessary to find a solution that will affect the reduction of unfavorable forces in the supports or that will reduce the large displacements occurring in the boiler walls.

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