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Weight Optimization of Buck Stays using Castellated Beams

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Abstract- The present water-tube boiler construction is based on membrane walls (tube wall panels) to form furnace envelope. Buckstay is a supporting element external to the boiler envelope stiffening the furnace against pressure differentials between gases inside the furnace and outside atmosphere. The membrane walls forming the furnace envelope alone could not withstand those pressure differentials. Hence membrane walls have been stiffened with the buckstay system placed to prevent large deformations. Buckstays are designed in accordance with any structural codes (IS 800, BS 5950 etc.) against shear, bending and axial stresses. Typical rolled & fabricated 'I' sections may be used as buckstay beam. This technical paper provides applicable loadings on buckstay, design considerations design procedure and to reduce the weight of buckstays using castellated beams.

Keywords: Water tube boiler, boiler construction, supporting structure, mechanical properties.

I. INTRODUCTION

A. Buckstay

Buckstaysare provided approximately every 2–3 m along the furnace height to hold the furnacein proper shape against internal gas pressures. A buckstay is an assembly of four girders supported on all the four walls and hinged at the corners to provide for expansion. The rise in internal pressure beyond the safe limit allows the gases to escape from the corners without damaging the tubes. Usually furnaces are designed for internal pressure fluctuations of ±200 mm wg. In case of large boilers with heavy back-end and cleanup systems, high induced draft (ID) fans are used. In a flame-out situation, from sudden termination of fuel supply (oil valve closing too suddenly or a master fuel trip), the furnace experiences a sudden decay in pressure. Mal-operation of dampers can also create a similar situation, called implosion. Then the furnace setting is designed for ±500 mm wg. Tie bars are really the hot parts, which are attached to the furnace tubes or the membrane panel. Buckstay clips or welding clipsattach the tie bars to the buckstays. Buckstays should be kept as cool as possible.

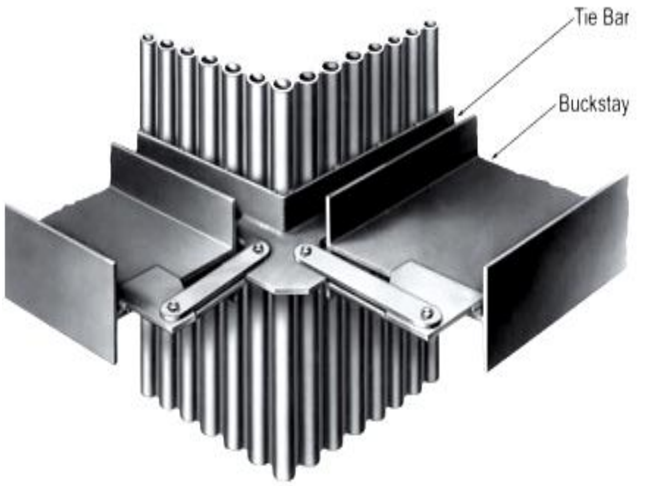

Fig-1-Corner connection of buckstay beam

B. Castellated Beams

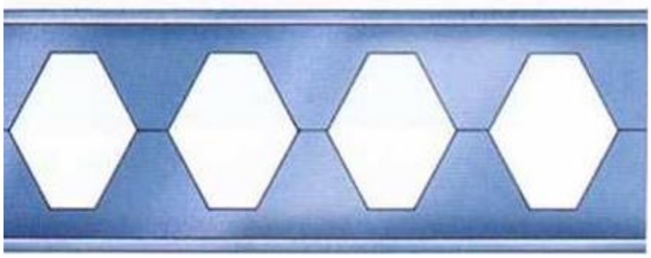

Fig-2- Typical castellated beams

A typical castellated beam has shown in fig:2 [1]. Castellated beams are the type of beams which involve expanding a standard rolled steel section in a predetermined pattern is cut into two halves. The two halves are joined together by welding and the high points of the web pattern are connected together to make a castellated beam. Castellated beam section helps to increase the section modulus of the beam.

II. LOADINGS ON BUCKSTAYS

Buckstaysusually experience the following loading:

1) Sustained(Operating) loading due to
   a) Furnace internal pressure
   b) Externally applied loads (if applicable)
   c) Bending moments caused by the eccentricity of the supports due to externally applied loads (if applicable)
   d) Wind load or Seismic loads whichever is governing at a particular site location through restraints [4].

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2) Transient loading due to
   a) Internal explosions,
   b) Internal implosions

III. DESIGN CONSIDERATIONS

A. Buckstay Components

Buckstays are attached on the furnace wall tube through buckstay components. The load transfer from furnace to buckstay beam is taking place through those attachments. Some attachments are provided to hold the beam in position without sagging due to self-weight of the beam. Corner plates are used to connect the four side buckstay to wrap around the furnace. The following are the essential components attached along with the buckstays.

1. Tie bar
2. Tie bar clip
3. Buckstay clip
4. OT post
5. Corner plates
6. Scalloped plate
7. Link plates
8. Pins

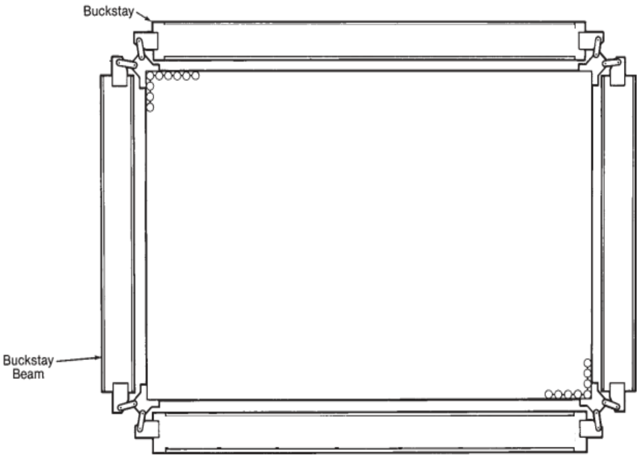

Fig-3-Plan view of furnace with buckstays

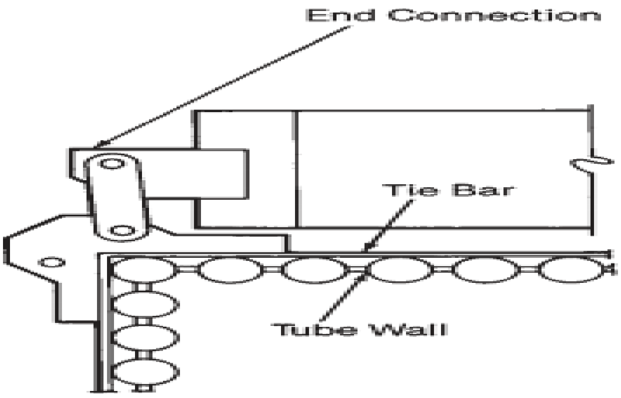

Fig-4-Buckstay corner connection detail

B. Buckstay Spacing

The buckstays have to restrain the tubes from bending and keep the furnace enclosure in position. Thebuckstay spacing should restrain the tube deflection, and the tube vibration should not coincide with the natural frequency of three cycles per second. Buckstay spacing shall be decided by calculating the following stresses induced on furnace tube.

1. Bending stress against the furnace inside pressure loads in sustained as well as transient conditions.
2. Axial tension or compression
3. Longitudinal stress due to internal pressure of fluid (Steam).

The addition of stresses will give the total stress induced on the tube. Induced stress shall be limited to allowable stress at design temperature of the tube material in accordance with structural code.

C. Buckstay Sizing

Buckstay sizing shall be decided by calculating the following stresses induced on buckstay beam.

1. Bending stress.
2. Axial tension due to reaction of adjacent buckstay.
3. Shear stress.

Induced stresses shall be limited to allowable stress in accordance with any structural code. Since buckstays usually located outside the furnace insulation, temperature correction factor is not considered in the allowable stress.

IV. DESIGN PROCEDURE

A. Maximum Bending Moment (M)

Maximum bending moment of the beam shall be calculated at worst case based on simple beam theory assuming a buckstay as a beam with simply supported ends. Bending moment diagram is drawn[1].

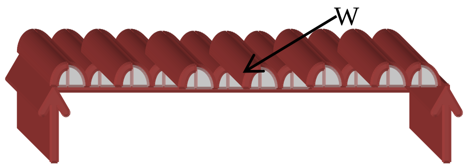

Fig-5-Simply supported bead with UDL

B. Shear Force (V)

Reaction forces of the beam at worst load case shall be computed and shear force is calculated. Shear force diagram is drawn. Reaction force of each buck stay is transferred as axial tension to adjacent buck stay, since the buck stays are wrapped around the furnace together by means of link plates.

C. Moment Capacity (Md)

Maximum bending moment shall be less than the moment capacity of the beam in accordance with the code provision. IS-800 ("General construction in steel code of practice")specifies the moment capacity of the beam under bending loading shall not be less than the actual moment.

$$M \leq M_d$$

--CL-8.2.2

$$M_d = \frac{\beta_b Z_p f_{bd}}{\gamma_{m0}}$$

--CL – 8.2.2

M_d - Moment capacity
β_b - 1.0 for plastic and compact sections
β_b - Z_e/Z_p for semi compact sections
Z_e - Elastic section modulus
Z_p - Plastic section modulus
f_{bd} - Design bending compressive stress from Table 13(a) –CL – 8.2.2
γ_{m0} - Partial safety factor for material (=1.1)

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D. Shear Capacity (Vd)

The maximum shear force shall be less than the shear capacity of the beam section in accordance with the code provision. Shear force shall be less than 0.6 Vd. IS 800 specifies the shear capacity of the beam as the following equations.

$$V_d = \frac{A_w f_{yw}}{\sqrt{3}\ \gamma_{m0}}$$

--CL – 8.4.1

A_w - Web area of the beam
f_{yw} - Yield strength of the web material
γ_{m0} - Partial safety factor for material

E. Deflection check

Buckstay actual deflection shall be calculated by means of deflection equation assuming beam with UDL. Buck stay deflection in sustained condition is normally limited to

- L/320 for stoker and similar industrial boilers
- L/500 for PF and large boilers

Buckstay deflection in transient condition
Need not be considered due to economical design.**5.**

V. DESIGN EXAMPLE

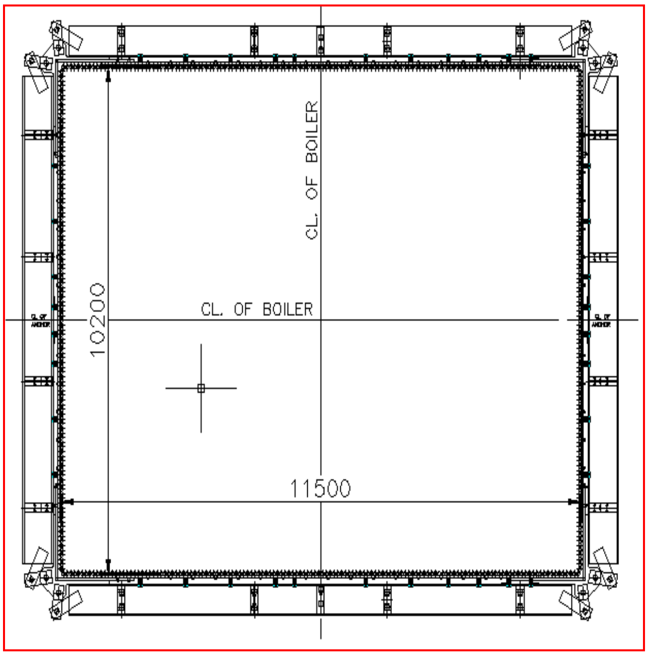

Fig-6-Furnace dimensions

A typical example for buck stay design has been done by manual calculation to prove the design optimization using castellated beams. Let a typical PF fired furnace with buck stay connection at one level has indicated in the above figure [1]. It has the following dimensional parameters and technical parameters.

Furnace width - 10200 mm
Furnace depth - 11500 mm
Design pressure - ± 500mmwc
Buckstay spacing - 4000 mm
Buckstay length (Front & Rear) - 10200 mm
Effective length - 2200 mm
Buckstay length (LHS & RHS) - 11500 mm
Effective length - 2700 mm

In this example furnace front side, Rear side, LHS and RHS buck stays separately designed in accordance with IS 800 using rolled steel beam "I" sections as well as castellated beam sections. The following values are calculated by using the equations mentioned in chapter-4 and tabulated [2].

Table-1-a

Furnace front& rear sidebuckstay		
Maximum bending moment	255.158	KN.m
Shear force	100.06	KN
Allowable deflection	31.875	mm

Table-1-b

Design using rolled steel "I" beam sections		
Front&Rear		
Selected beam size	NPB 500X200X90.7	
Unit weight of the beam	90.7	Kg/m
Allowable bending stress	204	Mpa
Moment capacity	357.54	KN.m
Shear capacity	626.37	KN
Actual deflection	28.69	mm

Table-1-c

Design usingcastellated beam sections		
Front&Rear		
Selected beam size	CB27X35	
Unit weight of the beam	52	Kg/m
Allowable bending stress	199	Mpa
Moment capacity	259.99	KN.m
Shear capacity	626.45	KN
Actual deflection	28.15	mm

Table-2-a

Furnace LHS & RHS sidebuckstay		
Maximum bending moment	324.343	KN.m
Shear force	112.815	KN
Allowable deflection	35.94	mm

Table-2-b

Design using rolled steel "I" beam sections		
LHS & RHS		
Selected beam size	NPB 600X220X108	
Unit weight of the beam	108	Kg/m
Allowable bending stress	205	Mpa
Moment capacity	517.68	KN.m
Shear capacity	722.69	KN
Actual deflection	26.94	mm

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Table-2-c

Design usingcastellated beam sections		
LHS & RHS		
Selected beam size	**CB27X46**	
Unit weight of the beam	68.5	Kg/m
Allowable bending stress	202.5	Mpa
Moment capacity	365.01	KN.m
Shear capacity	855.01	KN
Actual deflection	32.67	mm

VI. RESULTS AND DISCUSSION

From this design example it is clear that we shall achieve same strength of buckstay beam at reduced steel weight as well as cost without compromising the design. The following table gives comparison of buckstays using rolled "I" beams and castellated beams.

Table-3-a

	Rolled "I" beams	**Castellated beams**
Front and Rear side		
Moment capacity	357.54	259.99
Shear capacity	626.37	626.45
Actual deflection	28.69	28.15
Unit weight	90.7	52
Weight reduction	42.7 %	

Table-3-b

	Rolled "I" beams	**Castellated beams**
Front and Rear side		
Moment capacity	517.68	365.01
Shear capacity	722.69	855.01
Actual deflection	26.94	32.67
Unit weight	108	68.5
Weight reduction	36.6 %	

VII. CONCLUSION

By using the castellated beams instead of rolled I beams, we can have the overall weight reduction for one level is 39.18% for the above case. Based on this study it is recommended the castellated beam for boilers instead of normal rolled I beams so that we can have overall weight reduction as well as overall price reduction in the power plant. The overall price can be reduced by implementing this technique for all the future power plants as well as existing power plants if possible. While providing castellated beams, important practical considerations shall be taken care prior selection like thermal expansion provision of furnace, availability of maximum beam length in the market to avoid splice joint, LP test on weld joint and any equipment hindrance with buck stay

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[1] "IS 800 – 2007 – Code of practice for general construction in steel"
[2] "Boilers for power and process by Kumar Royaprolu"
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[4] "Castellated beam properties table"

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