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The Interactions Between Steam Piping and Boiler Outlet Headers in Fossil Power Plants

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THE INTERACTIONS BETWEEN STEAM PIPING AND BOILER OUTLET HEADERS IN FOSSIL POWER PLANTS

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ABSTRACT

This paper provides historical background, details, and some recent case studies of problem areas involving the interactions between steam piping components, including supports and boiler outlet headers, in fossil-fired power plants.

Historical background information includes the typical original equipment manufacturer practice of supplying thermal reaction values (forces and moments) at the boiler outlet. A description of the practice of adding moment restraints to the design of outlet steam headers to accommodate the torsional loadings from the steam piping lines is included. Focus of this paper is on the interaction problems between main steam and hot/cold reheat steam piping and their associated boiler outlet/inlet headers, but the same interface problems can apply to feedwater piping and the economizer inlet header.

The case studies will focus on the actual cause and effect scenarios on boiler and steam piping components due to malfunctioning supports. The influences of additional or loadings not specified will also be discussed. Recommendations for inspection and nondestructive testing monitoring programs, and current piping analysis modeling techniques applied to the piping/header interfaces are also presented.

INTRODUCTION

Interactions between steam piping and boiler outlet headers are not always fully considered in the original design or retrofit of these fossil plant components. This is surprising since they form an integral path for steam flow from the boiler to the turbine, and the components are seldom separated or isolated by a full anchor on the piping. Because of this, the loadings from one component can be imposed on or have an effect on the other.

In the original design of the equipment, interface locations in the piping are typically defined in the scope of responsibilities of the boiler manufacturer and architect engineer. Piping loadings are defined by the owner in the design specification. These loadings consist of pressure, weight, thermal expansion, and any defined additional mechanical loadings. The loadings are considered in stress analysis calculations to models of the piping and supports by the architect engineer for compliance to the rules of the applicable edition of ANSI/ASME Power Piping Code, B31.1 (1). Concurrently, the boiler manufacturer furnishes as- sold reaction values in the form of acceptable thermal expansion forces and moment values for the outlet header components. It has been the practice of Riley Stoker Corporation since the early 1970's to specify these allowable header thermal reaction values. The mechanical loadings due to weight, safety valve thrust and other sustained loadings for Riley-supplied components are accounted for in the design of supports. With the specification of allowable thermal reaction values, Riley also incorporates moment restraints, designed to accommodate the header reaction values in the torsional direction.

Case studies are presented herein which describe the effects on the piping and header components due to abnormal or not specified events, malfunctioning supports, and boiler retrofit projects.

BACKGROUND

Because there has been little construction of new utility fossil fired steam generating capacity during the past fifteen years, more reliance is placed on prolonging the life of existing equipment. This has been manifested by the many life extension and condition assessment projects performed, and by the subsequent emphasis on monitoring, maintenance, repair, replacement and retrofit of the components.

Utility fossil fired units have typically been designed for thirty years of operation, although this is not always stated as such in the original design specification. These boilers are now being operated well beyond this thirty-year period, due in part to component condition assessment programs and the implementation of the reported recommendations.

The older boilers were designed for base loaded operation, typically with two cold startups postulated per year. Today most utility boilers are operated in cycling mode to meet shifting load demands. There are many more cold, warm and hot startups per year, as well as typical load swings during each twenty-four hour period.

In the original design of the boiler and piping components for base loaded operation (to the rules of ASME Code, Section I, Power Boilers (2), and ANSI/ASME Code B31.1 (1) respectively), consideration for fatigue damage was not a primary concern. The current cycling and load swing modes of unit operation, however, makes fatigue evaluation of critical boiler and piping components essential in prolonging their useful life. Fatigue is not addressed in ASME Code Section I. It is considered in ANSI/ASME Code B31.1, under subsection 102.3.2, where a stress reduction factor is used for cyclic conditions for a defined number of full temperature cycles over the total number of years of operation. For a more rigorous fatigue evaluation of critical boiler and piping pressure components, the rules of ASME Code, Section VIII, Division 2 (3), and ASME Code, Section III (4), can be used as a guide.

Section 101, Design Conditions of the ANSI/ASME B31.1 Code defines the pressure, temperatures, and various forces applicable to the design of power piping systems. They are listed as follows:

- Pressure
- Temperature
- Dynamic Effects
- Thermal Expansion Loads
- Weight Effects

The following boiler or equipment events or conditions can cause significant effects on the steam piping and boiler header components.

- Safety Valve Operation
- Full Load Turbine Trip
- Water Hammer

Evaluation of the latter two cases requires the performance of a rigorous fluid dynamic analysis. This consists, in part, of developing fluid transient loads (force versus time), at each elbow and branch in a piping line. These dynamic load cases are not often defined in a piping system design specification. If a review of plant operating records reveals that such events have occurred, then these load cases should be included as part of a current full condition assessment of the main steam, hot reheat, and cold reheat piping lines in the unit. In such an analysis of a piping system, it is more accurate to include the boiler header and restraints with the piping model. This will ensure that the appropriate interactions from the specified loading cases are accounted for between the components. Another factor to consider in a piping reassessment program is that decreases in some Code material stress allowable values have been imposed in recent years. This is due to the results of long-term creep testing programs. This is especially true for ASME SA335, Grade P11 (5) material, which is commonly used for boiler header and steam piping components.

Another consideration in the reassessment of steam piping and boiler header components is for examination of the header moment restraints. These structures are designed to resist any torsional or twisting loads introduced by the piping. The examinations should include nondestructive testing of the welds attaching the restraint members to both the header shell and the building steel.

CASE STUDIES

Case 1 - Non Specified Loadings

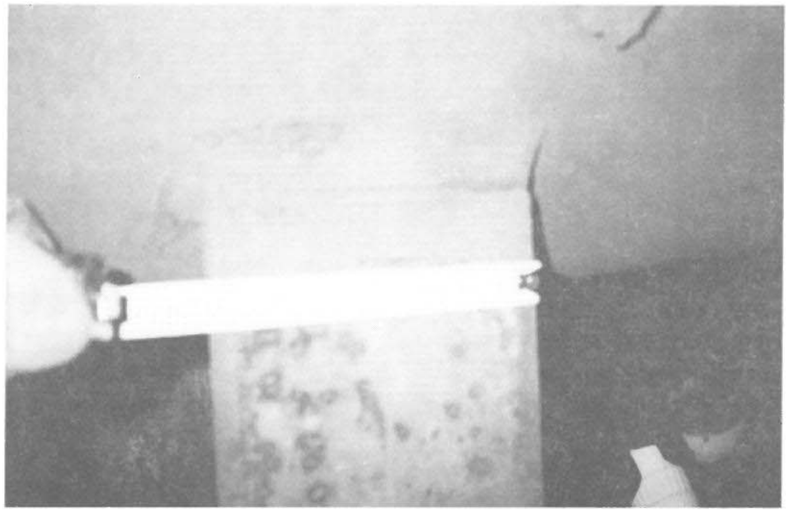
This case involved the complete reassessment of the main steam, hot reheat, and cold reheat piping systems associated with a 3,500,000 lbs/hr oil/gas-fired Riley boiler. At the time of the piping reevaluation, the unit had been in service for fourteen years. The assessment tasks consisted of a review of records, visual inspection and nondestructive testing of the piping components and supports. In addition, the piping lines received a complete stress analysis. The magnitude of some piping loadings caused the applicable boiler outlet/inlet headers to be added to the scope of work.

The headers were included as part of the piping models. This was beneficial in that it provided for the proper location of header restraints and anchors, local flexibility, and more accurate loadings on the header components.

A review of original boiler contract documents revealed much discussion and correspondence about exceeding the original as-sold allowable thermal stress range values at the boiler headers. This was ultimately resolved when Riley accepted the higher loadings from the piping, and stiffened the header restraints to accommodate them.

The owner's specification for the piping reassessment called for consideration of the loadings due to a turbine trip event. The unit had experienced this event several times in its history. This event loading was not specified in the original contract documents. For a full load turbine trip event, the turbine stop valve, located in the main steam line, closes in approximately fifty milliseconds. The abrupt closing causes a severe pressure wave to go back up, and then down, the piping line. This is commonly known as steam hammer. The short term steam hammer loadings on the piping components and supports can be quite high, and was true for the subject analysis. When the steam hammer loads were combined with the deadweight and thermal expansion loads, it resulted in several overstressed locations in the piping systems. Loadings on the boiler header nozzles, and stresses on the nozzles and some tees and elbows, particularly on the main steam piping, exceeded the code allowable values by up to a factor of two.

The effects of the higher loads and stresses were confirmed by visual inspection and nondestructive testing. This revealed several support locations, including header moment restraints, with deformed structural members and cracked attachment welds, as shown in Figure 1. Subsequent repairs, reinforced structural members, and added restraints were incorporated to accommodate the effects of the



Fligure 1 - Case No. 1
Reheat inlet header weld cracking on structural member of moment restraint.

steam hammer loads. Visual inspections showed that some supports were bottomed out. It was recommended that other supports be tested for load capacity and travel range. A methodology for the on-site load testing of constant force spring hangers on critical steam piping lines is described in the Reference 6 paper.

Nondestructive examinations of the piping pressure components revealed no serious problems, but a recommendation for scheduled monitoring was given as a check against future visible fatigue damage.

Case 2 - Steam Line Support Problems

This study involved the discovery of failed hanger lugs on the high temperature superheater and reheater outlet headers on a 600,000 lbs/hr oil/gas-fired Riley combined cycle boiler which was built in 1966. The failures were discovered during an extended unit outage for the in-kind replacement of the high temperature reheater tubing. The failures included two of four superheater header solid restraint lugs and three of four reheater header lugs. The hanger lugs were completely separated from the header shells, as shown in Figures 2 and 3. Portions of the weld metal were still attached to the headers.

The investigation of these failures included a complete visual inspection, with photographs, of the subject header components and of the main steam and hot reheat piping lines and their supports. Note that there were no moment restraints located on the outlet headers of this mid 1960's boiler. A metallurgical evaluation was performed on a failed lug plate from each header. Finally, a procedure for the repair of the subject hanger lugs was furnished.

Figure 2 - Case No. 2
Typical failed hanger support lug on
high temperature superheater outlet header.

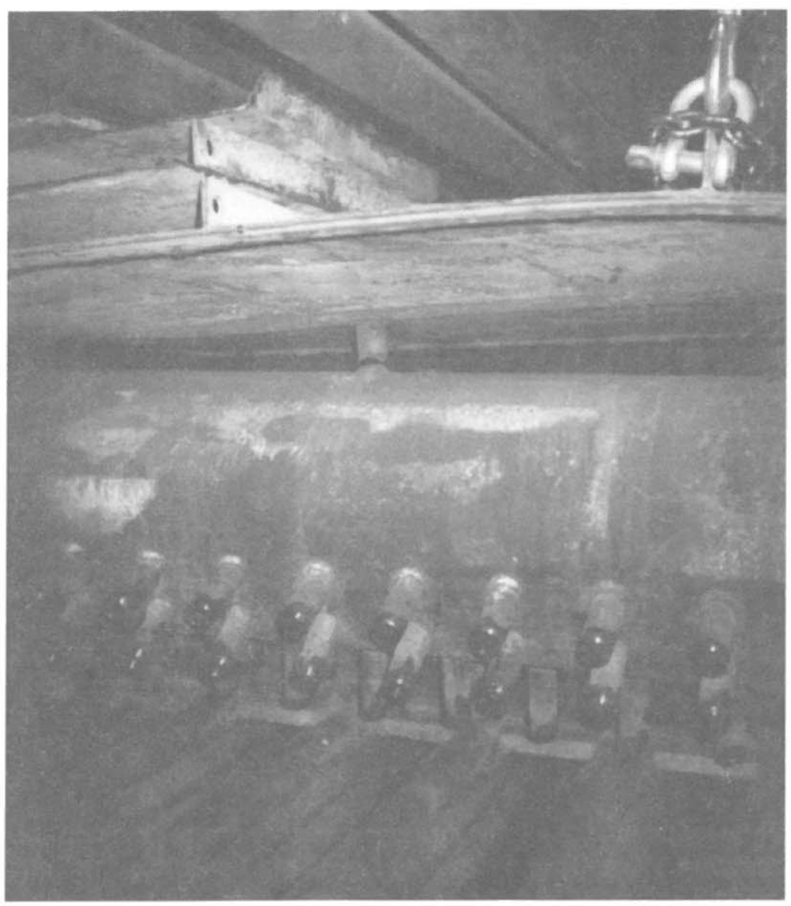


Figure 3 - Case No. 2
Failed hanger support lug on
high temperature reheater
outlet header.

An inspection was made of the hanger support rods for the two headers, including the attachments to the structural steel. There was no evidence of damage at these locations. Riley inspectors walked down the main steam and hot reheat piping lines to check supports. There was some evidence of abnormalities at several rigid, spring, and constant force supports and their structural assemblies. Some support rods were slightly tilted, and some support indicators were not in the "cold" position. At a dual constant force support location, one support indicator was at the "cold" position, while the other indicator was mid way between the "cold" and "hot" positions. Figures 4 and 5 show this pipe support location. There were also isolated regions of minor damage such as dislodged jacketing and insulation. At one location, there appeared to be an interference between the piping and an adjacent spring hanger.

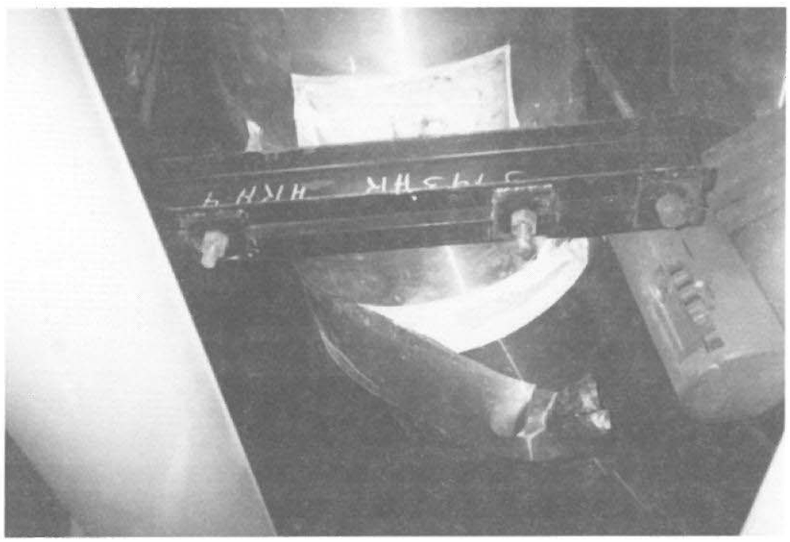


Figure 4 (top) and Figure 5 (bottom) - Case No. 2
Main steam piping constant force support assembly, which appear to be slightly tilted to one side.
Also, the parallel supports show different position indications in the cold condition.

According to plant personnel, the steam piping lines and supports were not inspected or monitored on a scheduled basis, and no analysis or non-destructive testing had been performed on the components in recent years.

The conclusion to the investigation was that the failures of the high temperature superheater/reheater outlet header hanger lug plates were attributed to localized overheating combined with excessive tensile loading. The overheating was confirmed by the metallurgy, and could be due to leaks at the boiler furnace roof to penthouse floor seals. Excessive tensile loadings were most likely transferred from the steam piping lines to the header hanger supports. As mentioned before, the walkdown inspection of the piping lines had revealed abnormalities which indicated some of the piping supports were not carrying the loads for which they were originally designed. The results of the metallurgy confirmed the excessive loadings on the hanger lug plates by the measured thinning at the failure surface, with localized cracking, and the presence of elongated grains in the microstructure.

A comprehensive listing of detailed recommendations was presented to the client, to minimize the repetition of similar failures. Recommendations included the performance of a complete condition assessment program for the boiler header and steam piping components including supports, with subsequent scheduled monitoring of the components.

Case 3 - Outlet Header Support Problems

Case 3 addresses interface problems between boiler headers and steam piping due to omissions resulting from a retrofit project. The 2,250,000 lbs/hr unit firing pulverized coal was originally built in 1965 by Riley.

During a weekend shutdown, the twin high temperature superheater outlet headers and inlet tubing were found to have dropped approximately six inches from their normal elevation in the penthouse of the boiler. Each of the outlet headers is supported by four spring hangers, with no moment restraints attached to the headers.

A review of records revealed that a full turbine trip event had occurred about one year previously. A complete visual inspection was made of the boiler, main steam line components, and supports. External steel for the header spring hanger supports was found to be twisted and deformed as shown in Figure 6. Additional steel was installed by the client to reinforce the structure at this location, as shown in Figure 7. A walkdown of the steam piping revealed that most of the constant force supports were bottomed out. Later, they were noted to be bottomed out while the unit was on line. The axial restraint on the main steam vertical riser was examined and the shear lugs were found to be twisted. They were subsequently replaced.

The focus of the inspection was shifted to the boiler, especially the furnace roof/penthouse floor seals. It appeared that there was not adequate support for the headers and the complete high temperature superheater assemblies which penetrate to the boiler furnace. A review of detail drawings confirmed this to be true. The original design called for welded scalloped angle plate supports at the roof seals. Apparently these supports, or an adequate substitute for them, were neglected in a superheater replacement/retrofit project completed about one year before.

This lack of adequate support at the furnace roof seals had resulted in the entire weight of the superheater assemblies being carried by the eight spring hanger header supports, causing subsequent distress to the main steam piping supports. These supports were designed only to support the headers and that portion of the superheater tubing located within the penthouse. A complete retrofit program was subsequently completed, with appropriate integral superheater supports installed at the furnace roof locations.

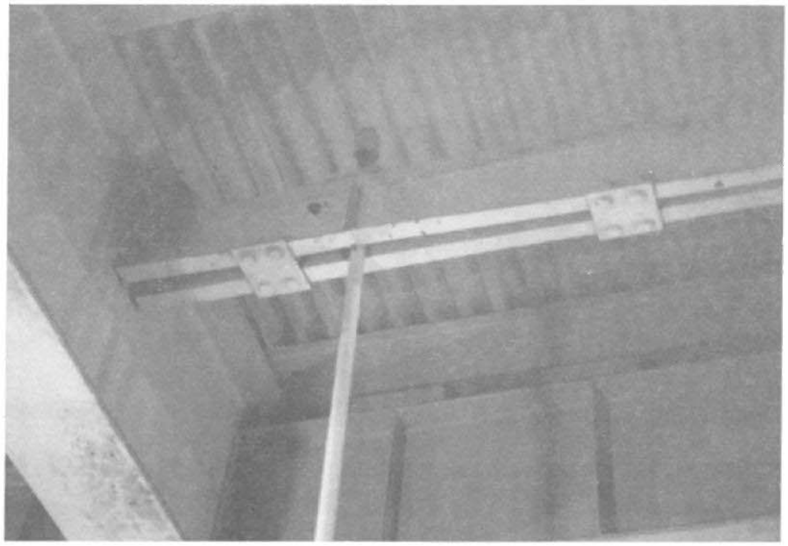


Figure 6 - Case No. 3
Twisted and deformed structural steel members due to overload at support location for high temperature superheater outlet header spring hanger.

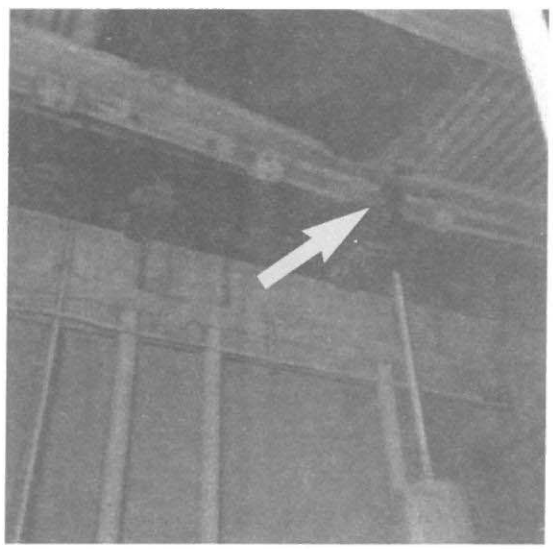


Figure 7 - Case No. 3
Location of added structural steel installed to reinforce the deformed steel members shown in Figure 6.

SUMMARY

The interactions between steam piping and boiler outlet headers in a fossil power plant are not always fully considered in the original design or subsequent retrofit of these components. The three case studies described above show how problems exhibited by one component can be imposed on and affect others.

One case study involved problems due to non specified loadings, specifically those from a turbine trip event. A second case study consisted of steam line support problems resulting in boiler header hanger lug failures. The third case study described a scenario where an outlet header dropped six inches due to inadequate supports at the furnace roof seals from a retrofit project. This resulted in serious overload problems reflected on the outlet steam piping and supports and their structures.

RECOMMENDATIONS

Potential interface problem locations should be identified and monitored as part of condition assessment programs. A review of available equipment records can provide valuable historical information of problem areas. The monitoring should include visual inspection of any header moment restraints and the component supports including their attachments to structural steel. Current physical condition, load capacity, and travel range of variable and constant force spring hangers should be assessed. On-site load testing can be performed to confirm the functionality of these supports. Nondestructive testing techniques should be used to confirm any suspicious findings from the visual inspections.

In any reassessment program for piping systems and headers, consideration should be given to evaluating previously not specified load cases, such as steam hammer loads due to a turbine trip event. For such an analysis program, the boiler header should be modeled as part of the piping to provide the proper location of header restraints and anchors, local flexibility, and determination of more accurate loadings on the piping and header components, including supports. As part of a current analysis program for header and piping components, the following items should also be addressed:

- Consideration of reduced stress allowable values, especially for SA335, Grade P11 material.
- Performance of a fatigue analysis for critical pressure components, considering the actual transient loadings experienced by the components to date.
- Performance of creep calculations and review of metallographic replicas for high temperature components to more accurately determine their remaining useful life.

REFERENCES

1. ANSI/ASME B31.1, Power Piping Code.
2. ASME Boiler and Pressure Vessel Code, Section I, Power Boilers.
3. ASME Boiler and Pressure Vessel Code, Section VIII, Pressure Vessels, Division 2 - Alternative Rules.
4. ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB - Class 1 Components.
5. ASME Boiler and Pressure Vessel Code, Section II, Materials, Part A - Specification SA335, Grade P11.
6. Gephart, J. and Kimball, L., "Case Study: Critical Steam Piping Constant Support Hanger Testing Programs," ASME PVP - Vol. 236, ASME Pressure Vessels and Piping Conference, New Orleans, Louisiana, 1992.