BANGING BOLTS—ANOTHER PERSPECTIVE

A look at the what and how of this noisy phenomenon

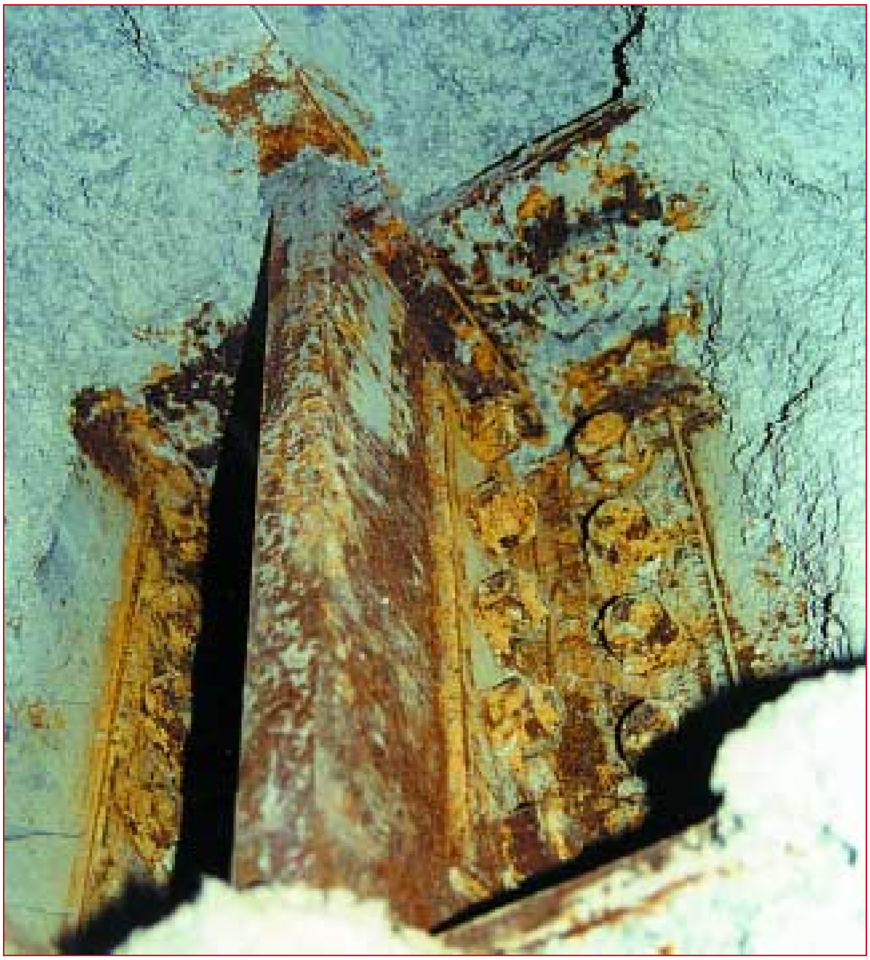

Figure 1: Typical exposure of fire protected moment connections.

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ONE OF THE PERFORMANCE PHENOMENA OF OCCUPIED STEEL BUILDINGS THAT RAISE OCCUPANT'S CONCERN is the possibility of banging bolts. Shortly after a building is occupied and for the next year or two, the occupants may hear loud and sharp noises that originate from within the structure. The noises are often described as sounding like a high-powered rifle shot. Typically this raises concern amongst the occupants as to the safety of the building. This paper will explore the cause of randomly occurring banging bolts and explain why occupants should not be concerned about their safety. The accompanying paper describes one investigation and develops a hypothesis for the cause; this paper examines other aspects of the banging bolt syndrome.

BACKGROUND

In general, the banging bolt phenomenon is attributed to the sudden slip of tightened high strength bolts (HSB) in a bolted connection. The bang is a sudden release of strain energy in the form of noise. Researchers involved in testing HSBs have for years observed the slip as noted in various publications (see references in preceeding article) and reported in figure 5.14 of "Guide to Design Criteria for Bolted and Riveted Joints" by Kulak, G.L., J.W. Fisher, and J.H.A. Struik, 2nd Edition, 1987, John Wiley & Sons, New York, New York.

In this test example, a slip of 0.06 in. or approximately $^{1}/_{16}$", is indicated for a 10 row lap splice connection. This amount of movement is the difference between the nominal bolt diameter and the bolt hole. In field connections with similar bolt rows, the maximum slip, if it could occur, would be substantially smaller because fabrication and erection tolerances would place some of the bolts dimensionally much closer to a bearing condition, therefore giving the bolts less distance to move when the slip occurs.

BANGING BOLT PHENOMENON

The banging bolt phenomenon randomly occurs in buildings, when bolted connections suddenly slip as the applied load overcomes the clamping force enduced friction in the connection. The author has investigated incidence of this behavior in building connections that can be divided into fundamentally three categories. The first category is a multi-bolt shear connection similar to the one described by Robert Schwein in the previous article where the beams support a composite metal floor system. The second category is the multi-bolt shear connection in industrial buildings without a floor system. The third category is a moment connection with multi-bolt web shear connection and welded beam flanges.

In several projects where the banging noise was reported, investigations were performed to find actual connection movement. It was observed that the sprayed on fire protection corroded the surface of the beam web and shear tab as shown in Fig. 1. Removal of the fire protection and corroded mill scale obliterated any evidence of joint movement having a magnitude of only a couple of hundredths of an inch. Subsequent wire brushing as shown in Fig. 2 further hindered detection of any joint movement but allowed examination of the joint to verify that weld fractures had not occurred.

Figure 2: Complete removal of fire pretection at edge of bolted connection.

The randomness of this phenomenon occurs because no sudden slip with the resultant "bang" will occur as long as any of the bolts in the connection group are already in bearing in the direction of the force. In steel framed buildings, the gravity weight typically pulls the supported members down so that one or more bolts will be in bearing. As a result, most buildings, each with hundreds of connections, will not experience the banging bolt phenomenon. However, whenever the erection procedure results in bolts that are nearly centered in the holes when tightened, such as employing drift pins, or other erection conditions the banging bolt phenomenon may occur. Ironically, as snug-tight bolts, slotted holes and shear tab usage became more prevalent, the incidence of banging bolts appears to have increased. The absence of paint on steel is also considered a variable that has increased the occurrence of banging bolts. As reported by P.C. Birkemoe, paint allows the connection to gradually slip into bearing without the resulting noise ("High Strength Bolting: Recent Research and Design Practice." *Proceedings of W.H. Munse Symposium on Behavior of Steel Structures—Research to Practice*, 1983, W.J. Hall and M.P. Gaus, Editors, ASCE, New York, New York.)

Connection Forces

The connection geometry that results in bolts located centrally in their respective bolt holes so that slip can occur is one of the contributing variables to banging bolts. The other critical variable is the force that causes the bolts to slip. Actually, a force exists in nearly every connection. The preceeding article by Schwein has identified concrete slab shrinkage as one of the possible causes of forces that induce slip in the connections of steel framed structures.

Another possibility is the timing of steel beam erection, the metal deck installation and pouring of the concrete slab. At each step the steel beam and the connection at each end will be at some base temperature. Subsequently, as the fire protection is applied and the building is enclosed, whether the building is heated or cooled to a stable temperature of approximately 70 degrees F may result in a temperature differential. The temperature differential magnitude from the time of bolt installation and tightening to enclosed building temperature is then a randomly occurring variable. A temperature differential of 20 degrees F or slightly higher is not unreasonable. For welded moment connections with bolted webs, flange weld shrinkage is another possible driving force source. Finally, as the building is occupied, the live load increases within the first few months and may become the triggering condition that causes a few connections to bang.

The force due to the temperature differential can be calculated from the basic thermal force condition if it is assumed that the columns at each end of a beam and the floors above and below provide a relatively high degree of restraint, yet another random variable. The axial stress in a beam for a temperature change when the framing at each end is assumed to fully restrained is given by:

$$f_a = E\alpha\Delta T$$

where:

f_a = axial stress, psi
E = modulus of elasticity, 29 x $(10)^6$, psi
α = coefficient of thermal expansion, 6.5 x $(10)^{-6}$, in/in/°F
ΔT = temperature differential, °F

The appropriateness in considering thermal shrinkage as a cause of the bangs can be demonstrated by a simple example calculation. A W24x55 beam is framed into shear tabs that are welded to columns at each end. The beam web is attached to the shear tabs with five ASTM A325 ⅞"-diameter bolts. The beam area is 16.2 sq. in. Assume a 20 degree F drop in temperature from the time of bolt installation to occupancy.

The axial stress is computed as 3.77 ksi corresponding to a beam axial force of 61.1 kip. Assume that the bolts have been pre-tensioned to the specified force of 39 kip and that the faying surfaces having a coefficient of friction of 0.3. Therefore, for the 5 bolts, the frictional force is 58.5 kip which is approximately equal to the thermally induced force. Based on the stated assumptions slip is possible if there are no bolts in bearing. The effect of the live load can be accommodated in the example by slightly changing one of the variables.

In moment connections, transverse shrinkage across the weld can be estimated using the AWS equation (AWS, "Welding Handbook", Volume 1, 8th Edition, 1991, American Welding Society, Miami):

$$S = 0.2A_w/t + 0.05R$$

where:
S = transverse weld shrinkage, in.
A_w = cross sectional area of weld, in^2.
t = thickness of flange plate, in.
R = root opening, in.

Appropriate assumptions for the variables in this equation and for axial displacement ($\Delta = PL/AE$) will show that weld shrinkage can also result in a force that exceeds the friction force developed by the HSB clamping force.

Schwein also raises some project specific issues that should be considered in the context of other investigations. The beam compressive force is attributed to differential shrinkage in the concrete slab due to variations in water/cement ratios. During other investigations, cracking has been observed in slabs along the girder lines and hairline cracking has also been observed at other locations, both of which could relieve beam compressive forces.

Similarly, in only one direction the metal deck could resist the concrete shrinkage forces. Petrographic examinations of the concrete in the suspect and adjacent slabs could predict the water/cement ratio and the related differential shrinkage potential accurately enough to isolate the floor banging locations. Obtaining accurate temperature and cloud cover records floor-by-floor throughout the construction sequence would allow one to estimate the temperature differential conditions. It is unlikely that the actual floor-by-floor erection fit-up conditions would be documented. Therefore knowing the temperature differential between the time of erection and the time of building occupancy only allows a qualitative evaluation of the induced thermal forces. Knowledge of slab cracking patterns, water/cement ratios and temperature ranges etc. would facilitate a more in-depth evaluation.

The bolt installation procedure is another contributing factor. However, contrary to C.J. Carter ("What are 'banging bolts' and how do they affect structural steel framing?", Steel Interchange, *Modern Steel Construction*, Vol. 39, No. 7, July, 1999)), whether the bolts are installed to a snug-tight condition or a prescribed pre-tension for a slip-critical connection is not significant in the occurrence of the banging bolt phenomenon. For ¾"- and ⅞"-diameter HSB properly installed by the calibrated wrench, turn-of-nut, tension control (TC) or load indicator method, the snug-tight condition typically results in bolt tensions close enough to the prescribed pre-tension for slip-critical connections. As a result, slip under thermal conditions and service loads will be a random occurrence independent of the installation technique.

Loosening connection bolts to induce banging bolts was an excellent concept that allowed Schwein to confirm the overall banging bolt hypothesis.

Summary & Conclusion

The reported occurrence of banging bolts has become more frequent in recent years. The bang occurs when high strength bolts (HSB) slip into bearing with the release of strain energy in the form of noise. Because it occurs so randomly in relatively few steel framed buildings constructed each year and for only a small percentage of the connections in those buildings, specific data is not readily available. The randomness can be attributed to fabrication/erection tolerances that for the most part result in HSB bearing conditions which prevents HSB slippage. The increase in banging bolts incidents also coincides with the increase in use of single plate shear tabs and slotted holes, a connection configuration that is likely to have all bolts in a non-bearing condition in the horizontal direction. The decrease in the use of painted steel members also contributes to the increase in sudden slippage.

Driving forces causing the banging bolt phenomenon can be attributed to concrete floor slab shrinkage, differential temperature conditions between the time of bolt tightening and building enclosure, and weld shrinkage in moment connections. Erection conditions that require forced alignment of steel members can also act as a driving force. The subsequent live load that results from building occupancy within the first few months to a year or so is the triggering force that causes the slip and resulting bang. It is probable that the differential temperature condition is the primary driving force because banging bolts have been heard in buildings without concrete slabs. In one instance, an industrial building with welded connections and without a concrete slab also experienced the banging bolt phenomenon.

In conclusion, as the accompanying article also indicates, the banging bolt phenomenon is an indication that a steel framed building is reaching its final equilibrium position but the banging is not of any concern regarding design or safety issues.

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