Slinging of structural beams

Structural beams types
INTRODUCTION
Contrary to the almost endless amount of slewing possibilities on trusses, the slewing methods on structural beams (or solid loads) are much less complex. Most structural beams have solid, closed cross sections, many made from hot rolled steel in ‘H or ‘I’ cross section shaped types. They have no possibility for any internal routing of the sling. When structural beams consist of a flat truss framework, often several meters in height, each of the chords in many cases is composed of a solid profile element. Even when the top and lower chords are composed of two separate elements (such as double angle or double channel) none of the elaborate slewing routings as found in aluminium trusses, is ever made on these ‘more complex’ steel beam structures. This is mainly the result from the fact that where we tend to used our trusses as comparable to lifting beams, they actually are more complicated in structure. A truss cross section has some of its properties shared with a single beam. The upper chords can be seen as the upper flange and similar the lower chords like the lower flange, and the diagonals are similar to the web plate in a beam profile. On the other hand a single steel H-section can be the chord in a flat lattice beam structure in a venue. Slinging of those is main point of attention here.

Fig. 1-0: Entertainment truss = beam + beam look-a-like.
Part 1: Beam types

A beam in many cases is a solid, or at least a fully closed, structural element. They have a limited number cross section shapes only and are available in a structural rated materials. The first picture (Fig 1-1) starts with the almost ubiquitous square entertainment truss size of 30x30cm, as a reference for the (over 320!) variations of slinging possible on this one alone.

Following in the figure are some of the more important beam cross sections, all of them to approximately the same scale. Wood historically is the oldest material for beam structures in houses, barns etc. Wooden masts of sailing ships have brought man across all oceans. Anyone ever having been in the roof structures of Medieval Cathedrals, Castles and City Halls would have been impressed by the skills of carpenters and architects rearranging complete trees into forming elaborate wooden truss structures. Today wood is still in use for roof beam structures of big buildings, although these days big wooden beams can be sold laminated sections.

Hot rolled steel I-beams are the next in figure 1-1. They exist since 1849 and in the early 1950’s have been accompanied by big square and round steel tubes in structural steel applications. These last ones definitely are no fun for a climbing rigger, but they are great for the D/t ratio of the wire ropes and basically any sling to be applied around them.

Finally the double angle is a conventional but still common type of beam, having chords that each essentially consist of two independent profiles and thus somewhat starts to resemble the spatial sling routing possibilities of an entertainment truss. Roofs where the structure is almost entirely made of big square and round steel tubes in structural steel applications. These last ones definitely are no fun for a climbing rigger, but they are great for the D/t ratio of the wire ropes and basically any sling to be applied around them.

A second type of box beam allows structural engineers to ‘tailor design’ the dimensions of the four flat plates that it is to be is made of. Similarly they can plan/-position internal plates for web stiffening, not visible after the beam is finished. For riggers this type of box beam means that work has to be done from the top and ‘split baskets’ are the way to go, where padding with burlap is not that simple anymore (see below). Otherwise slinging of these big M"F’s must be done from a hugely high aerial work platform, or as a rope access climber. Discussion of these various physical rigging techniques however is beyond the scope of these articles.

Fig. 1-2: Welded steel box beams.

Welded steel box beams tend to be much bigger. Two examples are shown in figure 1-2, both with a 30x30cm entertainment truss size in the same scale. Box beams made out of standard hot rolled HE-beams find a size limit because these standard beams have a maximum size in HEM1000 (1m high). The Prolyte B100R box truss has approximately the same height as this ‘double HEM1000’ beam. The difference in surface area of the truss aluminium round tubes and the beam solid steel flanges explains a lot on the difference in strength.

A thing that got unnoticed is the self weight of such a ‘double HEM1000’ beam: 710 kg/m. Compared it to B100R: 23 kg/m. A ‘double I’ box beam like this is not that easy to work as a ‘climbing’ rigger any more, but any 3m long sling will fit around it in a basket.

Fig. 1-3: Beam in standardized dimensions and mechanical properties easy to find in the various standard beam-tables.

Apart from those standardized hot rolled sections there also are welded ‘I-beams’ which are welded out of three hot rolled and cut-to-size plates: two for the flanges and one for the webbing plate. The plate thickness is often identical for all parts and the welding can be quite irregular, as shown in fig. 1-4. This type of I-beam can be found in certain area’s of the world, where steel rolling mills are not very abundant, and wages of welders are not very high. These beams are not standardized, not in dimensions, but also not in steel quality (tensile strength), in flange width or alignment, in cross section stability, nor in weld consistency of throat size, position or weld length. They certainly can be much more ‘tricky’ (unpredictable) for slinging purposes, and it is not imaginary that flanges would deform or buckle, thus this type of beam won’t be discussed any further.

Fig. 1-4: Welded I-beams – Non standardized
Double angle and T-shaped chords

Before those methods are to be discussed in detail, a bit more attention will be given to some other types of steel profiles as chord set-ups. One of the more traditional truss chords in roof truss beams is the use of double angle profiles. These have flat plates in between them as panel points that will provide connections for diagonals, verticals etc. (Fig. 1-5). The difference for a (wire rope) sling to pass around either top or lower chords is mostly related to the position and angle effect of the sharp edges. The demand for proper padding is clearly higher in the top than in the bottom chords. This steel angle profiles set-up resembles the T shaped ones, that do not have the risk of being squeezed together by the sling. A risk that is present in the double angles, and all other double member chords.

Cellular beams (Castellated beams)

The T- and inverted-T shaped beam cross sections in Fig. 1-5 resemble a remaining special type of steel beam: the cellular beams. These are slender I-beam shaped, in profile heights of a meter or more, with hexagonal or octagonal cells in the webbing plate. The beam is manufactured from a regular hot rolled I-beam of which the web plate is cut (blow torch, laser or water cutting), then repositioned as stacked and welded back again (hexagonal holes), or with flat steel plates in between the halves (octagonal holes).

Concrete beams

Finally reinforced concrete beams also can be cast in a great variety of shapes, to the custom specs of an architect or structural engineer. The one shown on the left in Figure 1-7 has a car riding surface integrated in the top flange, and the one on the right is equipped with consoles to support a layer of roof-, or floor-, cross-beam slabs. This feature can block the possibility of slinging this particular beam type. Occasionally concrete beams can have holes in the web part at regular intervals, shown as a hatched area, designed to allow various types of conductes like sprinklers, pneumatics or hydraulics, electricity etc. to run through them. If not in use for those functions, it could allow the rigger to be using them. That is, after the load capacity is well checked and a sufficient amount of padding is applied to prevent the abrasive effect of the stony edge of such holes. As a rule of thumb concrete is not used that often in very large spans (over 30 m) in venue structures but can be encountered in smaller ones. They seem to be a preferred type of beam in parking garages, for fire resistance reasons obviously.

Bigger is better?

As a rule of thumb the loading capacity of a beam will increase with its size, predominantly its height, and generally speaking the beam has to be higher when larger spans have to be made. But at one point the relationship between the self weight of the beam and its loading capacity will become disadvantageous. The next step in engineering will be a vertical ‘flat’ truss structure consisting of smaller beam elements now used as the top and bottom chords. In such structures it is up to the rigger which of both to be used for slinging for either straight down or bridle hitches, unless the venue has specific rules for how and where loads (thus the sling) can be applied. These topics are beyond the scope of this article, where the focus will be on the beam slinging methods. Increase in dimensions of a beam cross section can also have an effect on the practicability of slinging methods. This will be discussed later on.

Beam material properties

WOOD

Wood as a material is much softer than steel of a wire rope, and beams made of wood will get easily damaged in the upper corners when a wire rope is put around it. This will cause a number of problems, of which a small reduction in load capacity, easier access for fungi or bugs to eat their way into the wood, and dirty blisters in a rigger’s hand or fingers, are just a few. An advantage for sure is that a wire rope will not lose much of its capacity due to sharp edges. It causes its own improved D/d factor. Protection of wooden beams is very much different from one venue to another and in some venues special types of – beam dimension dedicated – protection devices are mandatory. In other venues slinging of the beams is not allowed at all, and slinging can only be – in the direct hitch mode - to a number of lifting eyes fixed to the beams at regular intervals. In yet other venues only a few types of sling materials are/were allowed (webbing or round slings only, with a steel sling as secondary for fire hazards), or even these had to be combined with special custom ‘protectors’. Finally wooden beams that are impossible to sling with the roof skin layer straight on top of them, are the only ones where a drill with wood spade bits can very quickly make a hole through them for insertion of threaded rods and lifting eyes. The risk of ending up with ‘Emmentaler beams’ is not imaginary.

A general remark about wooden beams in old monumental or listed buildings, is that wood will continue to decay over the years – or centuries. All kinds of natural agents that would attack dead trees on a forest floor will try to do the same thing with dead trees in a roofing structure. Hundreds of years old listed building like churches, castles, market roofs or town halls should be regularly inspected and maintained for bugs, woodworm, molds, fungi etc. Some of these biological agents tend to be mainly active on the inside of the wood, and avoid direct light. Superficially the damage can be much less than in the interior of the beam. If there is any reason for doubt make sure the inspection report is handed over, which should be available in any listed building. And if not a few random tests with a knife or screwdriver can be very clarifying. When the steel part disappears all the way up to the handle into the sponge-like wood there shall be no rigging from such a beam, and better not from all the other ones either. When in doubt? GS!
FIRE PROTECTION COATINGS - ALSO EASILY DAMAGED

A thing that has gotten more attention since ’9/11’ is the protection of steel against extreme temperatures caused by fire. Beams can be clad by all kinds of fire protection materials and often these will be soft as wood - and slinging is not allowed. Solutions for making rigging still possible can change from one venue to the next. ‘When in doubt: GS!’

STEEL (AND SHARP EDGES)

Denying that I or HE beams have sharp edges is moving the illusions by the performer on stage into the technical department as well. For slinging of steel beams to be lifted as loads in the building construction industry using wood planks as padding a common practice to protect the wire rope. Although some hot rolled profiles like Channels, Angles or T-shapes can have relative smooth rounded edges but some other edges can still be sharp.

What is sharp? The diameter (d) of the wire rope can be compared to the Diameter (D) of the object it is going around. Than the D:d (the bending factor) can be expressed for all kind of slinging materials and for each one tested what the minimum factor needs to be. This is internationally laid down in standards and publications and expressed as D:d = 6:1. Documented research gives a D:d factor of 6:1 as the lowest number bringing 6-strand wire ropes to an efficiency of about 95-100%. As more often happens in Germany it’s all a bit bigger. D:d could just as well be expressed as R:r, when looked at the Radius of the object that the sling has to pass around. If this 1:1 makes a wire rope loose about 50% of its capacity, riggers must be aware of the objects that they are slinging. Any sharper ‘turn’ than the 1:1 should be avoided, surely not in rigging for the entertainment industry. However most of the modern day ranges of hot rolled I-beams have a flange radius of ca 1mm, as seen in Fig. 1-11 of a HEA200 beam. Not like a knife to our skin, but very sharp for a 10mm diameter (~1 tonne) wire rope. It surely helps if in the entertainment industry any lifting accessory of material is to be loaded to only half of its capacity anyway. The added (doubled) factor of safety is not a luxury demand when we look at the majority of the steel beams that form the structures where to rig from.

This sharp edge problem (D:d ratio) for the sling body was reasonably covered by padding with many layers of textile. Obviously wood blocks are not an option, and many dedicated devices also are not, with the risk of falling as the main problem and the time it takes to get them in position as another one. As shown in Fig. 1-12, multiple folded burlap bags are used for a number of basket steels. In case of burlap bags might be missing or not enough other things like old towels, T-shirts, carpet tiles, bed linen or stage drapes in many layers will do as well. They must be multiple folded (or rolled) into a thick layer of material. But always in as many layers as reasonably possible. These textiles are not put on those beams to remove any dust. Cleaning of beams is done by the riggers anyway, as can often be observed on their clothes (and hands and faces) once they have finished their actual work.

Just like the beams of wood those of steel can also gradually disappear. Not the biological agents are the problem, but corrosion can be a serious problem when roofs are leaking. In most of the beam profile types the corrosion of steel is easier to spot than the decaying of wood. As soon as the traces of rust are visible it is better to check the area’s where it is present. Riveted node points have been reported to have lost almost all structural integrity, but bolted or welded area’s can be just as vulnerable for corrosion. Always watch out for traces that point to corrosion and make sure it can’t be a hazard for safe rigging.

Slinging methods classification?

These next diagrams can be found for general classification of load slinging methods with single slings or endless slings. Fortunately the cross sections of loads almost always seem to be round, contrary to most of our steel beams. If the possible issues of a slinging method is discussed, it should not be confused with issues of sharp edges. But in the end when all implications of slinging are to be taken into account no issues with impact on safety, should be forgotten either.

When looking further along the line for examples of slinging schemes like this one below are also found very often, where a basket is shown with vertical legs only. Inclined leg types are called bridle hitches, that’s OK, but there are two separate slings to start with. Can’t a basket have inclined legs? What if there is only one hook to be lifting that load? Is there a reason for the round and square loads in these particular slinging methods?

Compare these two diagrams and keep wondering… Maybe one - or two – more can help?

It is almost like chokers will go to round objects only and baskets must be applied on square load? Basket legs can be bridles after all, and whenever the slings are inclined they can be straight into the hook. In the last diagram a new enigma rises: How on earth is that vertical sling applied to that load? And what if the two bridle hooks - in that last diagram- would be joined below the load?

All of this does not really help in getting a clear idea on slinging methods classification.

MAYBE (AMERICAN) OSHA CAN HELP US OUT? (OR THE GERMAN BGI’S)

After all these guys (and dolls?) represent the Law. And will possibly enforce it
when they might visit our workplace. [Such visits are too often only happening when the accident has happened. We should just hope and pray it can’t be because of faulty slinging.]

The diagrams below are from the OSHA web site (July/August 2013): (Note: what is in italic is done by the author, not by OSHA)

VERTICAL AND BRIDLE HITCHES * [1]:

CHOKER HITCHES *[3]

A number of remarks * by the author of this article:

1) Are Vertical and Bridle Hitches to be considered one (single) category?
2) What do those ʘ symbols mean exactly? Connection points? Sling end terminations?
3) Is this about chokes (as in header and pictures?) or about baskets (as in the text)?
4) The picture is missing the Quadruple bridle choke and the Double Basket sling?

Even OSHA is messing up! It is probably a all a bit more complicated that it looks at first sight. More on the slings themselves in the next article, followed by the slinging methods. And only after that the implications of combining beam types + sling types + slinging method types can be discussed.

1 The exception might be a so called ‘running bridle’ or ‘triangle bridle’. A better name perhaps is a ‘reefed bridle’, but basically these are no bridles in the real sense of the word. They should be considered as a huge basket going around two (chords of separate) beams. Reefing greatly increases horizontal forces, and bridles like this should only be applied with utmost care and proper calculations.


3 Patented in that year in the French speaking part of Belgium, that with the UK, France and Germany was a major contributor to the Industrial revolution in Iron and Steel.

4 Officially known as HSS (Hollow Structural Sections) or CHS (Circular Hollow Sections) and RHS (Rectangular Hollow sections).

5 Either a “cherry picker” or aerial working platform is needed, or a catwalk next to it. The special “rigging beams” that were introduced in entertainment venues in Holland since the mid-1990’s are square or round hollow sections exclusively.

6 Beams using double angle were already in existence where a flat steel plates served as the web, and on top and bottom edges the angle iron were hot-riveted to them. These days riveting technology has more or less died out completely.

7 The indoor cycling arena, “Het Kuipke” in Gent, Belgium has a roof structure in aluminium I-beams.

8 The lower (tension) chords in the bow truss structures of the “Amsterdam ArenA” are manufactured like this.

9 The surface area of the B100R truss is 4072 mm², the ‘double HEM1000’ has 88842 mm². The Moment of Inertia is one of the ways of expressing strength. The ‘double HEM1000’ is 1444598.104 mm⁴, and the B100R is 235,2.104 mm⁴. The difference in weight helps to explain why riggers love beams of steel and trusses of aluminium.

10 Spanish architect Santiago Calatrava has designed steel-meets-concrete building structures of impressive beauty.

11 Paraphrasing Jamie Hyneman (Mythbusters): “When in doubt…C4!”

12 Of course other wire rope constructions, and specifically the low rotation or Dy-form rangens will need (much) higher D:d ratios, but who in the World will used this type for slinging of loads. If everything in life has to be based upon a total lack of knowledge what is the use of science and education anyway?

13 Double as high that is: BGR 151 states: “Eine scharfe Kante liegt vor, wenn der Radius der Kante kleiner als der Seildurchmesser ist.” A sharp edge is found when the Radius of the Object is smaller than the wire rope diameter. So then it must read R:d > 1:1 or Rc < 2:1 to not call it ‘sharp’ anymore. How come there is always someone to complicate things?

14 Another thing is the price of some of those gadgets, that can almost be as much as the wire rope sling itself.

15 The myth that only a maximum of eight folds is possible has been properly busted by Mythbusters in 2007, and there is no law against rolling up burlap bags, and than flattening them when the wire rope(s) are put over them.
Rinus Bakker, Consultant & Trainer of Rhino Rigs.

Rinus (‘Rhino’) started in 1970, doing lighting & sound in a rock venue. An inherited interest in structural strength made him swing to rigging in the early 80s, since which has become his core business, in every possible aspect. Since 1994 he has participated in rigging & safety standardisation committees in Holland and abroad. In 2000 he was co-founder of ARGH, the first in the world to support professional entertainment riggers.

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