Abstract

This document compares the design of a rectangular shaped telescopic boom weldments currently used on cranes, boom trucks, aerial work platforms and other similar lifting equipment, to the state-of-the-art multi-bend shaped boom profile. We explain how the use of high-strength steels in multi-bend designs can help reduce the overall weight of a machine, improve lifting payload capacities and reduce manufacturing costs compared to rectangular shaped boom sections. This information can impact designs of lifting equipment.

CIP Manufacturing S.p.A. and Perazzi Engineering e C. SRL

esamera@cipmfg.com

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Rectangular Boom Section Vs Multi-Bend Boom Section

Executive Summary

The main purpose of this document is to outline the design criteria of a multi-bend boom profile which is preferable over a rectangular boom profile, for a telescopic boom application used on cranes and aerial work platforms.

In order to optimize the best design for lifting equipment in specific working conditions, decisions about the most appropriate boom profile sections must take into account the following elements.

- ✓ ***Stress:*** *design of telescopic boom sections in order to obtain material stresses lower than the allowable value for the type of steel used. Allowable stress depends on the ratio between the yield stress and factor of safety. Stresses below the allowable yield stress and factor of safety prevents permanent deformation in boom structure under normal operating conditions.*

- ✓ ***Deflection:*** *design of telescopic boom sections in order to obtain a deflection required to the type of service the machine must perform. Allowable deflection for a telescopic crane mounted on a truck, cannot be the same for a pick & carry crane: the latter lifts, telescopes the load and travels with the load hanging at end of the boom; boom truck cranes lifts once the load is completely stabilized.*

- ✓ ***Buckling:*** *the telescopic boom sections ability to resist a catastrophic failure of a structural member which subjected to high compressive stress. Permanent deformation of the boom section will prevent the operation of the boom structure.*

- ✓ ***Welding:*** *location of welds need to be strategic where stresses are the least to improve the fatigue life of the boom.*

- ✓ ***Effects by localized pressure on wear pads:*** *strategic placement of the wear pads are critical in order to reduce localized loading and stresses on the boom structure.*

- ✓ ***Wear Pad life:*** *strategic placement can optimize wear pad life while providing self-centering characteristics between boom sections for uniform and smooth operation.*

- ✓ ***Market demands:*** *design of boom sections in order to improve lifting capacity, vehicle payload and reduced fuel consumption.*

- ✓ ***Marketing trends:*** *design of boom sections as state-of-the-art technology, innovation and hallmark in lifting equipment market.*

Profile and Cross Sections

The Figure 1 below, compares three different profile sections with the same overall outside dimensions.

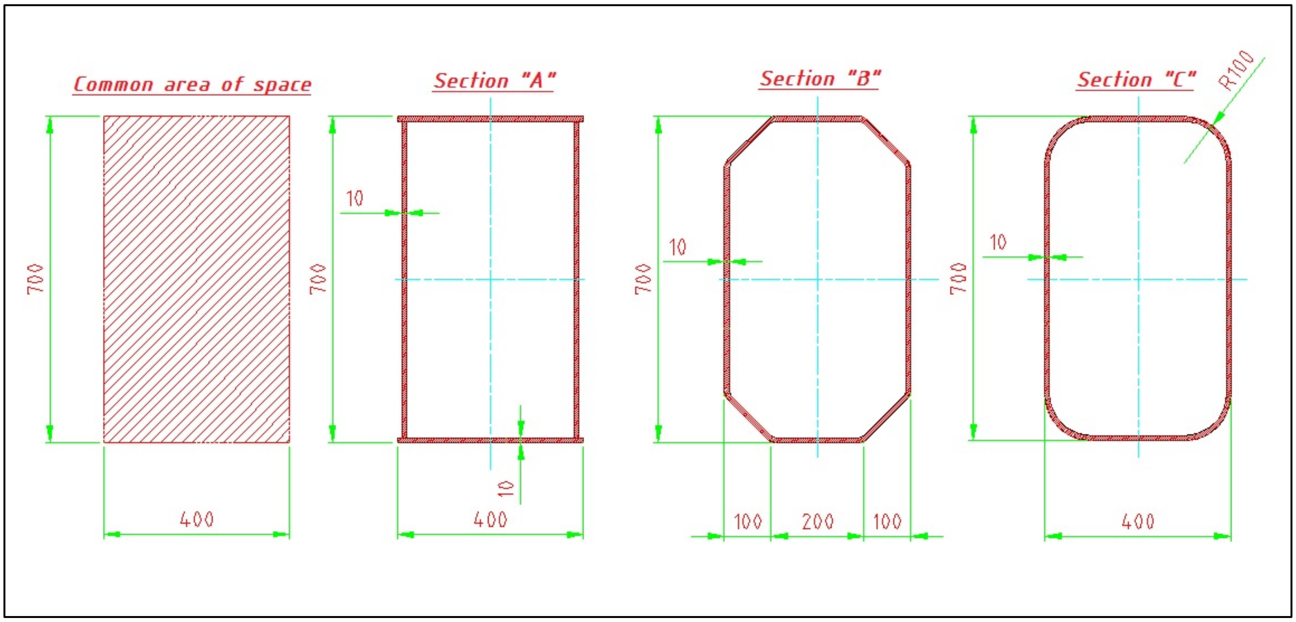

Figure 1, profile section comparison

Optimum Boom Profile

The Multi-bend profile section shown in Figure 2 combines the profile of sections "B" and "C" provides the best solution for strength, resistance to buckling and improved fatigue life.

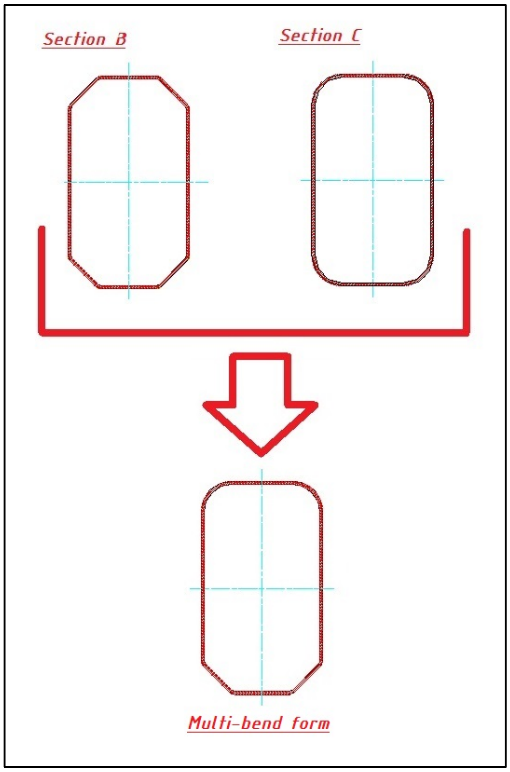

Figure 2, optimum profile section

- ✓ ***Stress***

Telescopic booms are subject to high stress from bending moment. Calculation of stress is as below:

$$\sigma = M / W$$

where:

M, bending moment

W, modulus of resistance to bending (directly proportional to moment of inertia J).

According geometrical properties of each profile section, we have:

$$J_{\text{Section “A”}} > J_{\text{Section “C”}} > J_{\text{Section “B”}}$$

$$W_{\text{Section “A”}} > W_{\text{Section “C”}} > W_{\text{Section “B”}}$$

Therefore, the relationship of stress as a function of section profiles are shown below:

$$\sigma_{\text{Section "A"}} < \sigma_{\text{Section "C"}} < \sigma_{\text{Section "B"}}$$

It is important to emphasize the stresses between rectangular and other profiles can be reduced by selecting an appropriate grade of steel.

✓ *Deflection*

Boom deflection ‘f ’ is inversely proportional to moment of inertia ’J’, as already written at the paragraph above, we have:

$$J_{\text{Section "A"}} > J_{\text{Section "C"}} > J_{\text{Section "B"}}$$

Therefore, we can determine the relationship of deflection between profile sections:

$$f_{\text{Section "A"}} < f_{\text{Section "C"}} < f_{\text{Section "B"}}$$

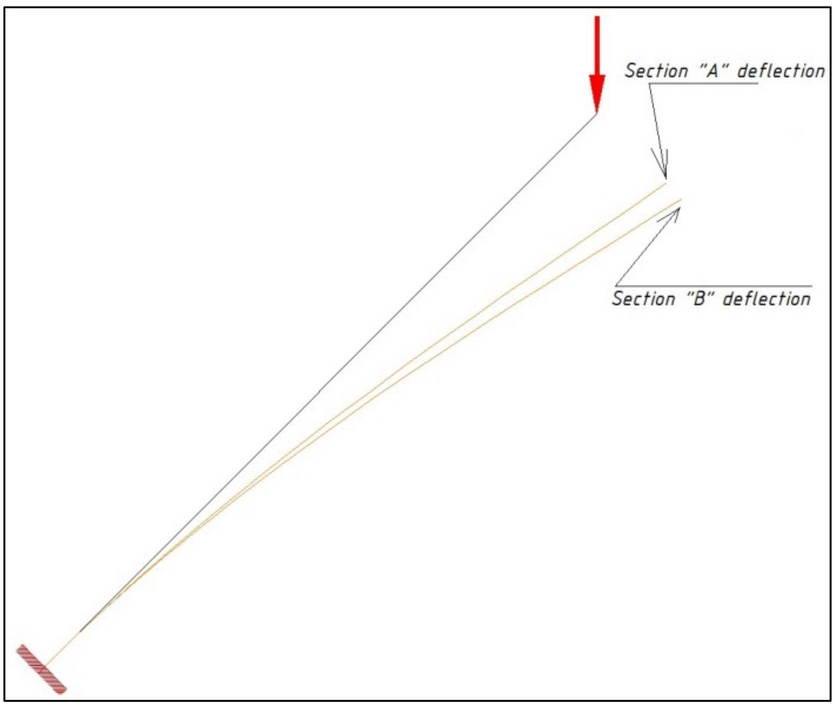

Figure 3, relative deflection differences between profiles

Section ‘A’=Rectangular Profile Section “’B’=Multi-Bend Profile

✓ *Buckling*

Buckling is a phenomenon where elastic instability usually occurs to flat surfaces. This phenomenon occurs when compression stresses and large geometrical sizes of a flat surface are present. A high probability of buckling can occur suddenly without any advance warning.

All boom sections have bottom and side plates and are subject to buckling. However, due to larger flat surfaces inherent with rectangular boom profiles, buckling is more likely to occur more than multi-bend boom profiles.

- ✓ ***Welding***

Fatigue stresses and welded joints are inherently incompatible. The best way to solve this incompatibility is to position welded joints where stresses are very low.

In a boom section, stresses created by bending moments reach maximum levels on the top plates (tensile) and on the bottom plate (compression), stress are nearly zero close to neutral axis. See Figure 4 below.

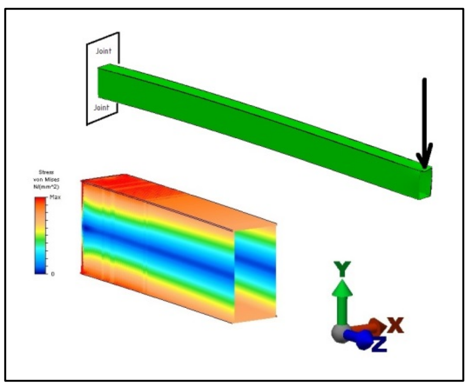

Figure 4, Stress gradient with applied bending forces

Rectangular boom sections are inherently designed with welded joints placed in the outermost corners where high stress values can occur. In multi-bend boom profiles sections type “B” and type “C” are manufactured by joining two formed “U”-shaped plates and weld joints are purposely designed along the neutral axis in the direction a bending moment. See Figure 5 below.

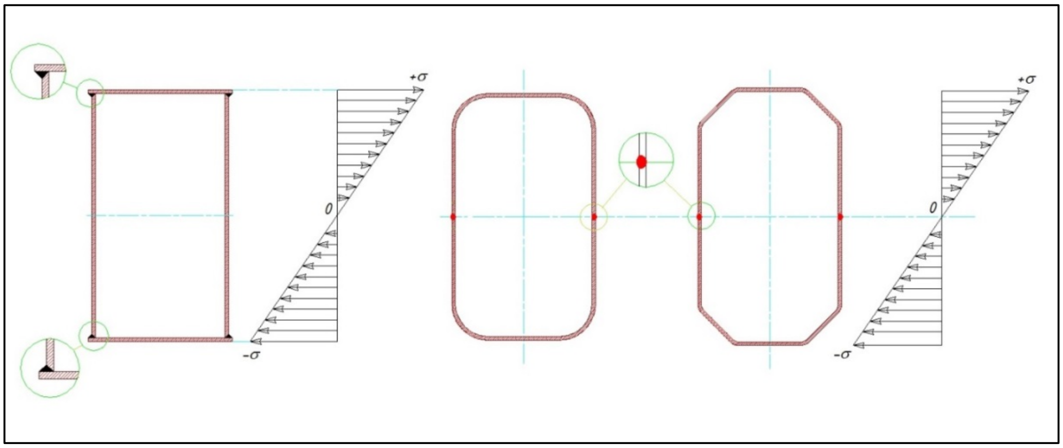

Figure 5, locations and relative value of stresses when a vertical bending moment is applied

- ✓ ***Localized pressure on wear pads***

Contact of wear pads deflect plates: this condition are not as prominent with section type “C”, instead it is an important consideration for section type “A”. See Figure 6

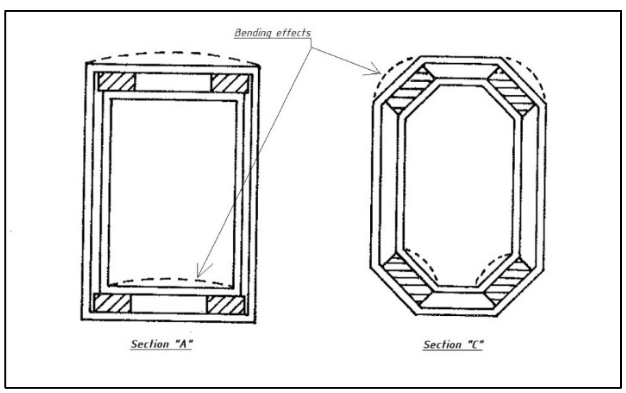

Figure 6.
Wear pad contact point showing localized effects between rectangular profile sections vs multi-bend profile sections.

✓ *Wear pads effects*

For section boom type "A" and type "B" stresses on wear pads are at highest close to the outer edges of the wear pad and can have higher replacement frequency over the life of the machine. With section boom type "C" stresses on the wear pads is generally equally distributed over the width of the wear pad surface, thereby reducing the replacement frequency. See Figure 7.

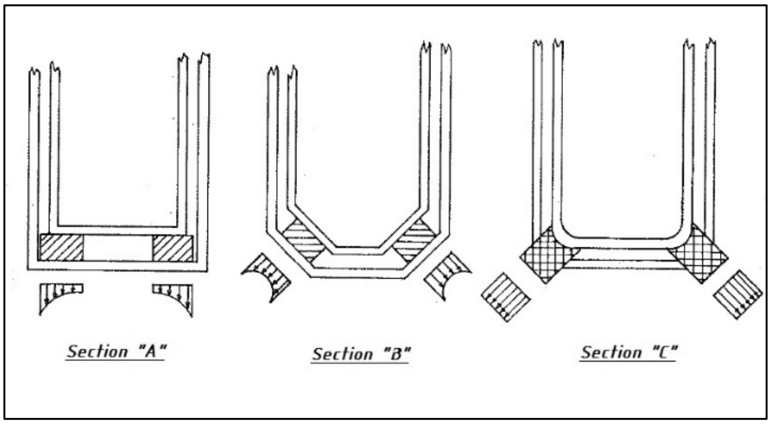

Figure 7, Stress distribution on wear pads relative to boom profile sections.

One must consider uneven wear of the pad surfaces due to localized uneven stress can cause undesirable positioning of boom sections between wear pad replacement intervals.

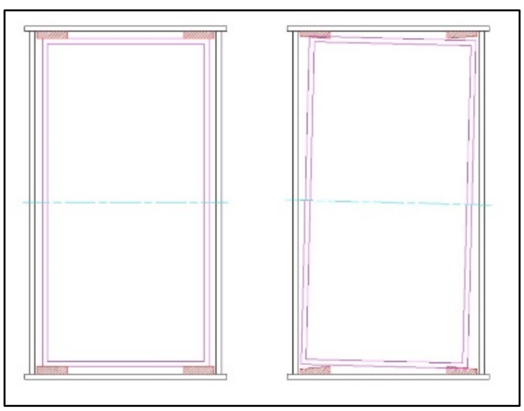

Figure 8.

- Image on the left shows how the boom sections are ideally position and equally spaced between boom sections during installation.
- Image on the right shows the how the boom sections can be position unequally spaced between boom sections due to uneven wear of pads.

✓ *Market Demands*

To meet recent market demands telescopic boom type equipment must be designed with larger capacities. Customer's insatiable appetite for larger lifting capacities, manufacturers must resort to designing solutions without increasing boom weight while meeting all regulatory and company specific safety design requirements.

The selection and use of high-strength steel have been an easy choice to obtain the goal of lighter weight boom sections with higher capacities. However, the use of high-strength steel needs careful evaluation about boom profile section for two main reasons as follows:

- *The potential for buckling doesn't depend on mechanical properties of the material.*
- *Consideration to improve fatigue life at the welded joint.*

A rectangular profile section has a favorable modulus of bending resistance but does not alone lend itself to just use high-strength steel. A high risk of buckling can happen and welds are positioned in the areas where maximum stresses can occur.

Multi-bend profiles are better suited with high-strength steel for the following reasons. Improved fatigue life of the welds by locating the weld joint in the low- stress area. The likelihood of buckling is solved with multi-bend formed sections (see Figure 9 below, where on an aerial platform boom, buckling on the side wall is solved by designing in a slight bend at the weld joint).

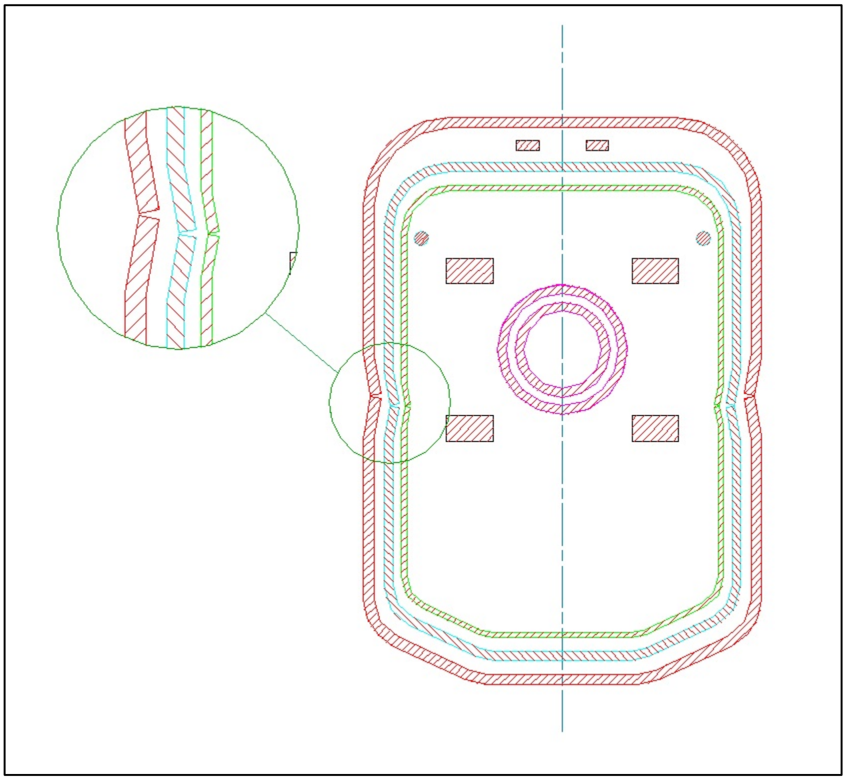

Figure 9.

Multi-bend profile sections designed with high-strength steel have the following advantages:

- Lighter overall boom assembly weight
- Lighter machine weight which helps reduces overall machine fuel consumption during travel and operation.
- Lighter machine weight also reduces braking effort during stopping.
- The machine's center of gravity providing improve stability during operation.
- Ability to increase lifting capacities which is limited when mild steel is used or designed with rectangular profile sections.
- Allows to attached crane or aerial work platform structures to a commercially purchased truck, in lieu of a purpose built truck chassis
- Possibility for on-highway equipment to travel without special highway permits.

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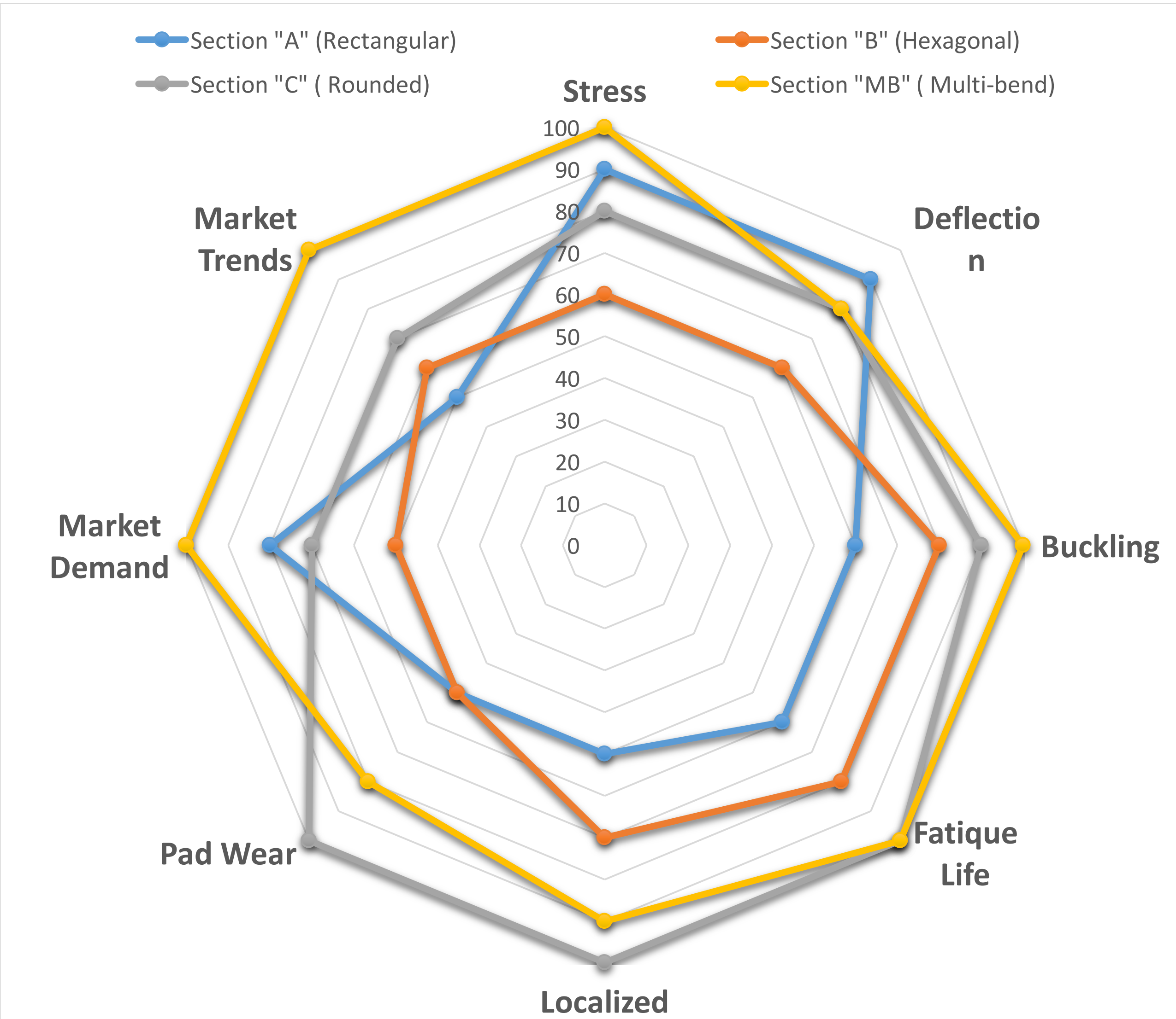
✓ ***Marketing Trends***

The market of telescopic boom machines, multi-bend profile section booms is a sign of efficiency and technological advancements. Multi-bend profile sections allow flexibility to many design and manufacturing issues that were difficult to resolve. Multi-bend designs have become the hallmark for the best manufacturers in telescopic boom world.

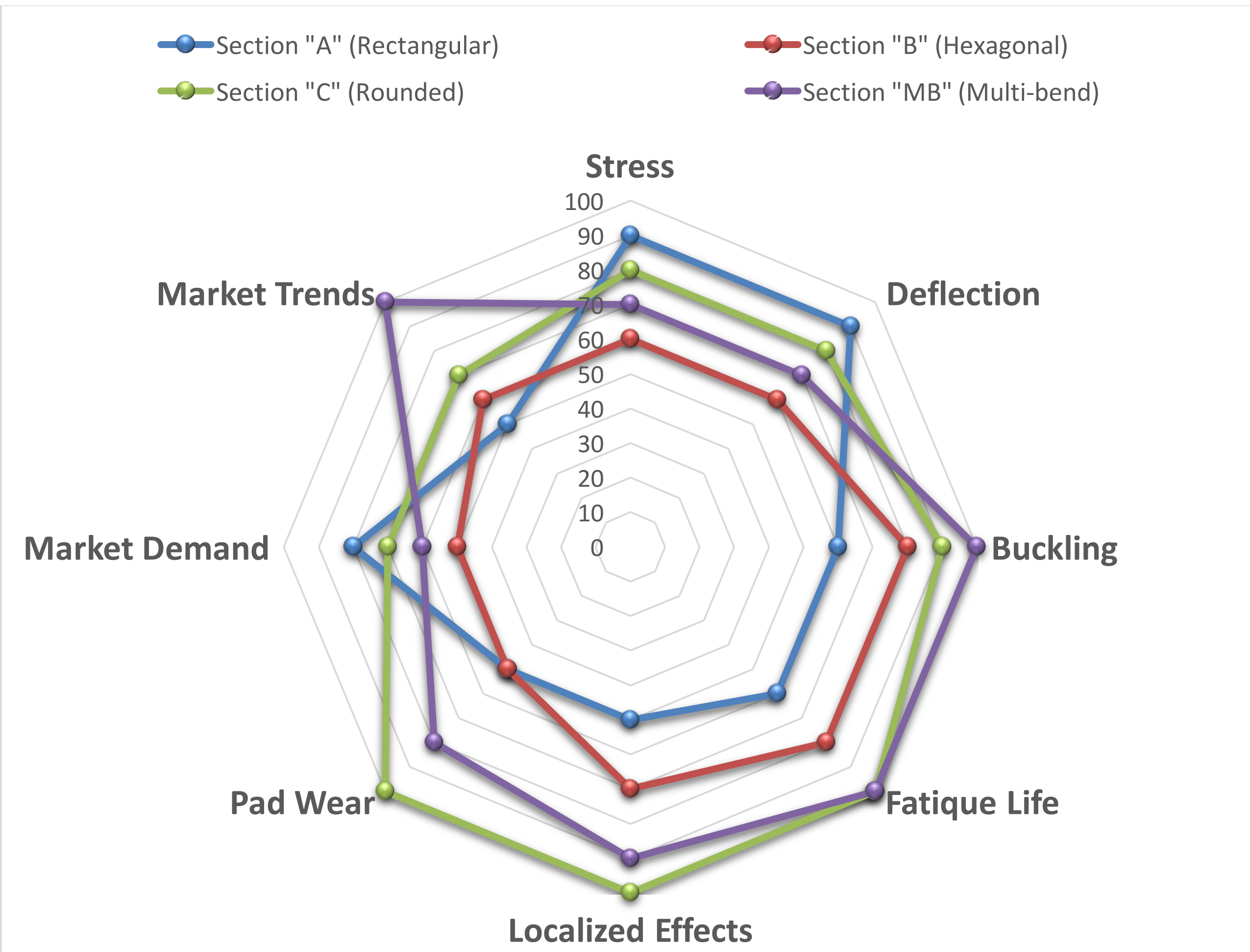
Section Comparison Using High Strength Structural Steels (> 60ksi, 400 Mpa), Figure 10



Relative Rating Scale

Very Poor 0 10 20 30 40 50 60 70 80 90 100 Very Good

Section Comparison Using Mild Structural Steels (< 60ksi, 400 Mpa), Figure 11



Relative Rating Scale

Very Poor 0 10 20 30 40 50 60 70 80 90 100 Very Good

Multi-bend form section: advantages/disadvantages

<u>Advantages</u>

- High resistance to buckling
- Longer fatigue life, especially at weld joints
- Localized deformations are minimized
- High efficiency during extend and retract operation (less friction = energy savings)
- Well suited for use with high strength steels
- Less weight, i.e. less dead loads = energy saving)
- Overall machine weight is reduced, improved fuel consumption and shorter braking distances
- Allows for increased payload or lifting capacity
- Axle loads are reduced when traveling
- Improved stability, i.e. lower center of gravity of the machine
- Market trending with State-of-the-art-technology,

<u>Disadvantages</u>

- Low resistance to side deflections (lateral forces)
- Deflection slightly increases

Evaluation between rectangular boom and a Multi-bend boom section profile

✓ *Costs of manufacturing process*

This section evaluates the manufacturing of a telescopic boom characterized by three boom sections profiles. This is a case study where a lifting equipment manufacture did a cost study to convert from a rectangular boom section profile to multi-bend boom section profile.

- **RS**. An existing rectangular boom design section where: three telescopic boom sections (one fixed and two telescopic) with a rectangular profile using S355J2 steel grade and has a yield stress of 51 Ksi (355 MPa).

- **MB 500**. Proposal #1 is a multi-bend boom section profile design having three telescopic boom sections (one fixed and two telescopic) designed as a multi-bend profile using S500MC steel grade, Domex® 500, with a yield stress of 72.5Ksi (500 MPa).

- **MB 700**. Proposal #2 is a multi-bend boom section profile having three telescopic boom sections (one fixed and two telescopic) designed as a multi-bend profile using S700MC steel grade, Strenx™ 700, with a yield stress of 100 Ksi (700 MPa).

Table 1: Rectangular Sections (RS)

Inner section	**Height, inches/ mm**	**Width, inches/ mm**
Overall Dimensions	12.4/316	7.3/186
Side plate, thickness	0.12/3	
Top and bottom plates, thickness	0.16/4	
Side and Top plate length	330.7 / 8400	
Intermediate section		
Overall Dimensions	14.5/368	9.0/230
Side plate, thickness	0.12/3	
Top and bottom plates, thickness	0.19/5	
Side and Top plate length	330.7 / 8400	
Outer section (fixed)		
Overall Dimensions	16.9/428	11.0/280
Side plate, thickness	0.16/4	
Top and bottom plates, thickness	0.24/6	
Side and Top plate length	338.5/8600	
Overall Boom (3 x sections) Weight, lbs./ kg	**2,383 / 1,081**	

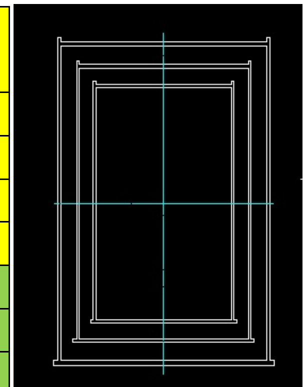
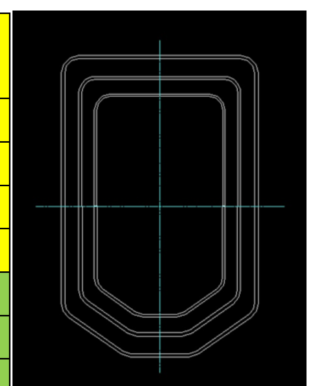


Table 2: Multi-Bend (MB500)

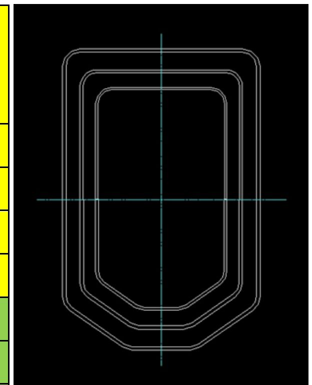
Inner section	**Height, inches/ mm**	**Width, inches/ mm**
Overall Dimensions	12.4/316	7.3/186
Top formed plate thickness	0.12/3	
Bottom formed plate thickness	0.16/4	
Top and bottom formed lengths	330.7 / 8400	
Intermediate section		
Overall Dimensions	14.5/368	9.0/230
Top formed plate thickness	0.16/4	
Bottom formed plate thickness	0.19/5	
Top and bottom formed lengths	330.7 / 8400	
Outer section (fixed)		
Overall Dimensions	16.9/428	11.0/280
Top formed plate thickness	0.19/5	
Bottom formed plate thickness	0.19/5	
Top and bottom formed lengths	338.5/8600	



Overall Boom (3 x sections) Weight, lbs./ kg	**2,178 / 988**

Table 3: Multi-Bend MB700

Inner section	**Height, inches/ mm**	**Width, inches/ mm**
Overall Dimensions	12.4/316	7.3/186
Top formed plate thickness	0.12/3	
Bottom formed plate thickness	0.12/3	
Top and bottom formed lengths	330.7 / 8400	
Intermediate section		
Overall Dimensions	14.5/368	9.0/230
Top formed plate thickness	0.12/3	
Bottom formed plate thickness	0.16/4	
Top and bottom formed lengths	330.7 / 8400	
Outer section (fixed)		
Overall Dimensions	16.9/428	11.0/280
Top formed plate thickness	0.16/4	
Bottom formed plate thickness	0.19/5	
Top and bottom formed lengths	338.5/8600	
Overall Boom (3 x sections) Weight, lbs./ Kg	**1,951 / 885**	



The overall weight saving between the three boom profiles is summarized in Table 4 below:

Table 4: Overall Weight Savings between boom profiles

Boom Profile Weights for 3 sections	**Weight lbs. / Kg**	
Rectangular Section	2,383 / 1,081	
Multi-Bend (MB500) with Domex® 500 Steel Grade	2,178 / 988	
Multi-Bend (MB5700) with Strenx™ 700 Steel Grade	1,951 / 885	
Savings between boom section profiles		
Rectangular Section vs Multi-bend (MB500)	205 / 93	
Multi-bend (MB500) vs Multi-bend (MB700)	227 / 103	
Rectangular Section vs Multi-bend (MB700)	**432 / 196**	**Maximum Weight Savings**

✓ *Weight Savings Gains*

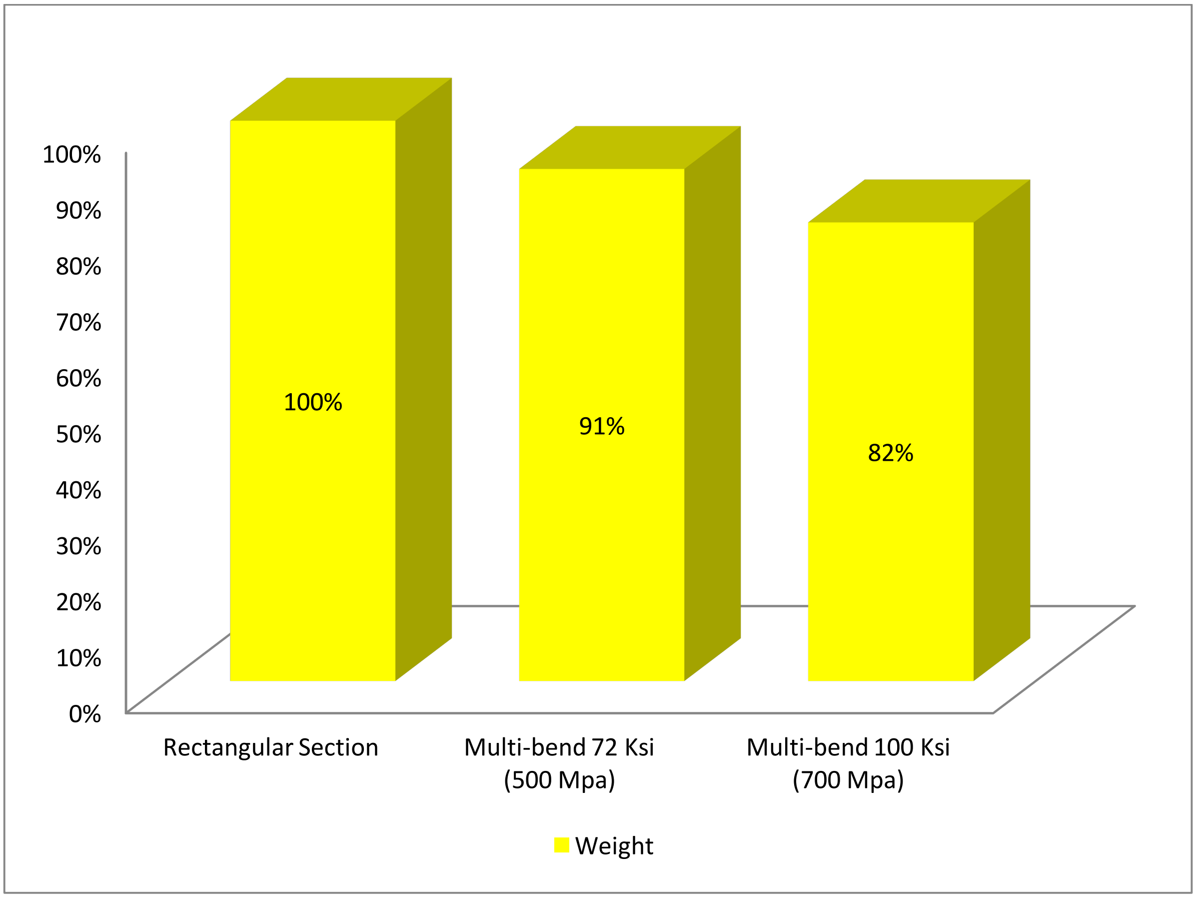


Figure 12: Relative weight savings between boom section profiles

Weight savings obtained in multi bend telescopic boom weldments provide many overall machine performance advantages.

✓ *Capacity Improvement*

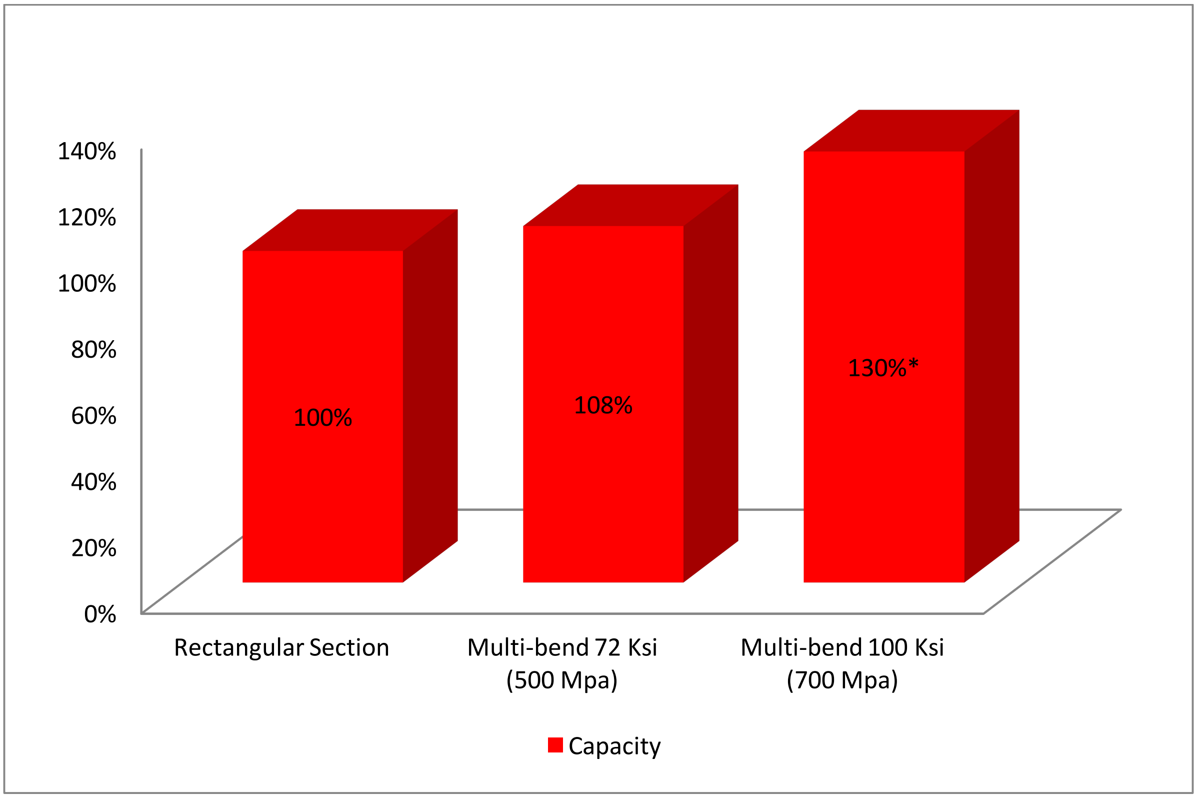


Figure 13: Relative load capacity gains between boom section profiles

Note: *30% capacity gain was accomplished on an Aerial Work Platform application

Multi-bend designs allow for increasing lifting capacity while maintaining the same stowed and operational space requirements as rectangular boom section profiles.

✓ ***Production costs***

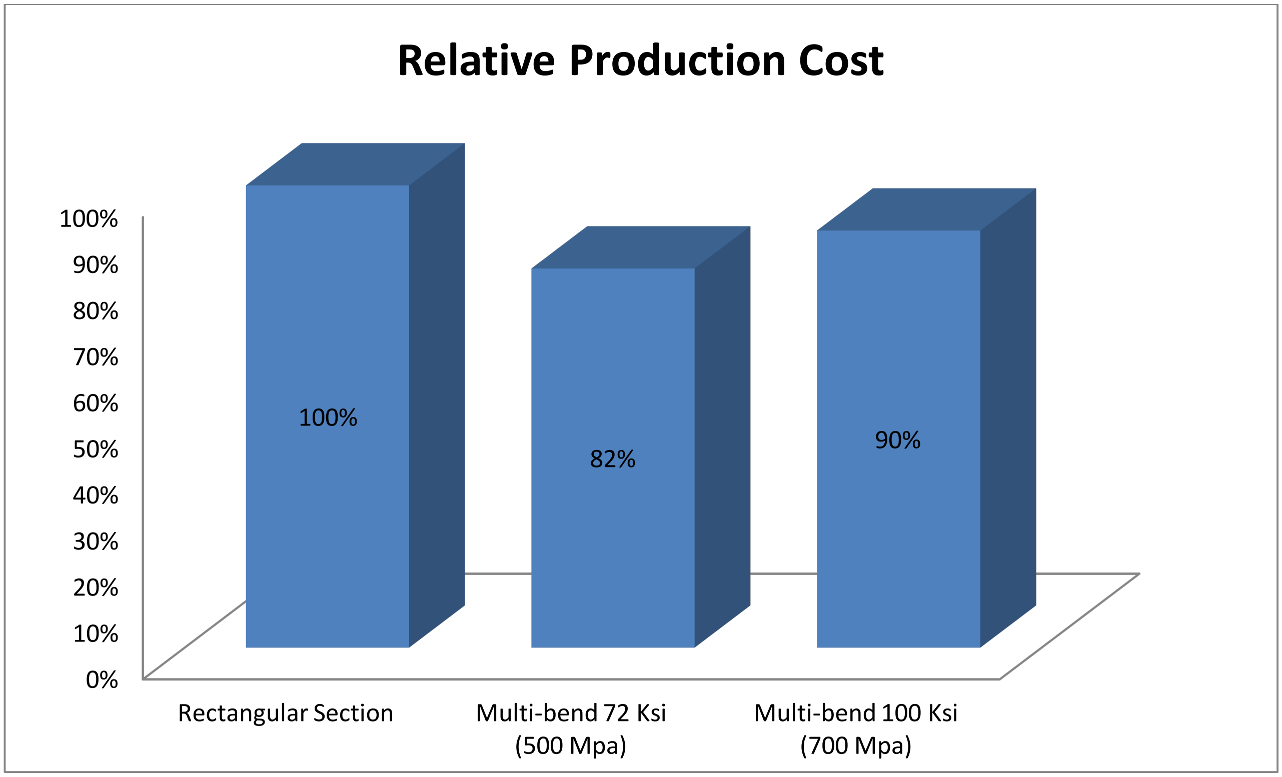


Figure 14. Relative overall production costs of multi-bend boom section profiles compared to rectangular boom sections.

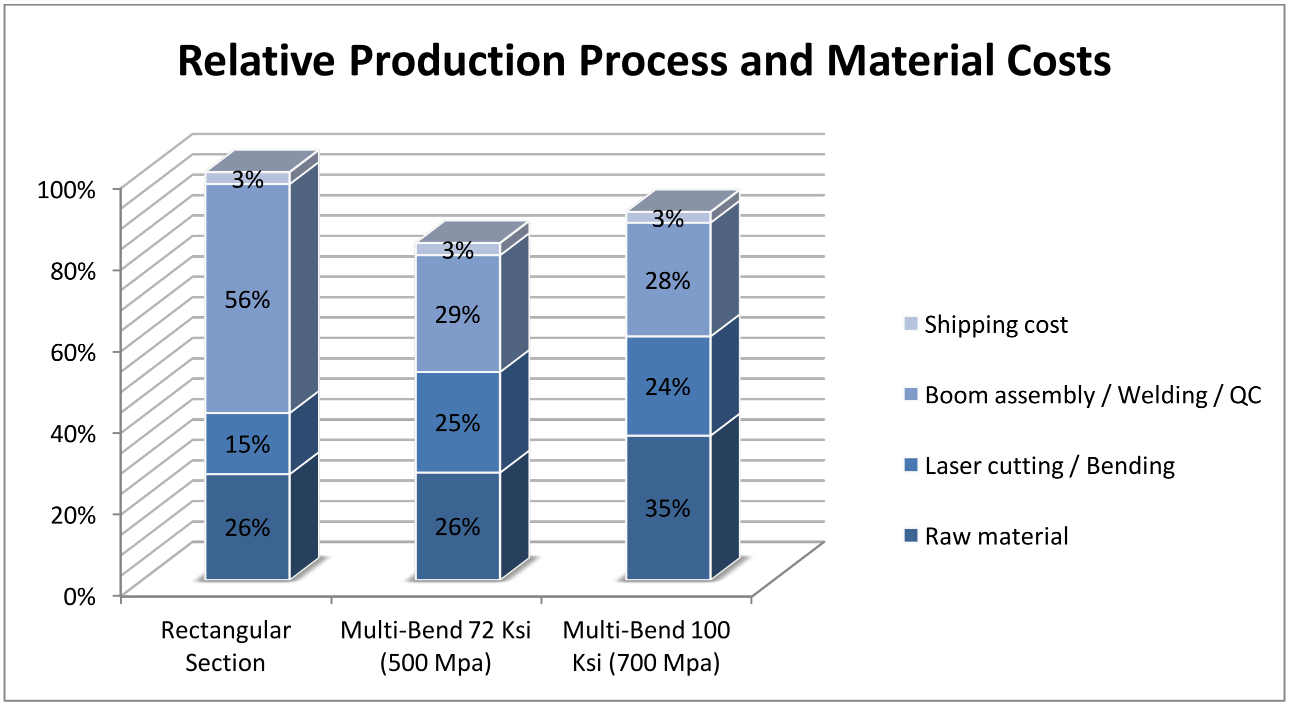


Figure 15. Relative production process and material costs between multi-bend boom section profiles compared to rectangular boom sections.

The major contributors which reduce manufacturing costs between a rectangular boom section profile and a multi-bend boom section profile are as follows.

Manufacturing Operation	Rectangular Boom Section Profile	Multi-Bend Boom Section Profile	Multi-Bend Boom Advantages
Laser Cutting	Requires 4 steel parts per boom	Requires two steel parts per boom	Less time to laser cut required plates
Assembly to weld	Requires setting up 4 steel parts to create profile	Only two steel parts used to setup a boom profile	Less man hours to setup for welding
Welding	Requires 4 to 8 welds- 4 outer welds and if needed, 4 inner welds	Only two welds required along the neutral axis of the boom	Less time to weld and weld materials
Quality Check	Requires inspection and cleaning of 4 to 8 welds	Only clean and inspect two welds	Less man hours spent on inspections

Figure 16

Conclusions

Multi-bend boom section profiles have many design and cost advantages on lifting equipment where side loads are minimal, i.e. aerial work platforms – self-propelled and truck mounted, telescopic hydraulic cranes – all terrain, rough terrain, truck mounted and boom trucks.

If moderate sides loads are expected on lifting equipment, i.e. reach stackers, container handlers, material handlers, excavators etc. a rectangular boom section profile is the boom section profile of choice.

In conclusion, there are multiple design and manufacturing costs advantages for a multi-bend boom section profiles using high strength steels, > 60 Ksi (400 Mpa), over the traditional rectangular boom section profiles. Modern day high strength steels, manufacturing techniques and current technology has allowed designers to create lighter weight machines, increase load capacities, improve fuel consumption, reduce manufacturing and operating costs.

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Ing. Fabrizio Perazzi

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