

A Finite Element Analysis on the Troughed Belt Turnover

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Abstract

Belt turnover is an effective way to reduce material carry-back on the return side. It reduces environmental contamination and maintenance work, and improves return idler roll life. Flat turnover has been the dominant belt turnover method. For extra wide and high strength belt, the concern is that the flat turnover requires long length, large space, and causes high sag and stress in the belt. Troughed belt turnover, pioneered by the Mordstein turnover, is introduced to address these concerns, where the belt is folded into a troughed or semi-circular shape by guide rollers along the turnover. However, there isn't a clear and effective design method on the troughed turnover due to its complexity. There are a wide range of mechanical designs to induce the troughed belt turnover, without a clear understanding of their effectiveness. This study uses the finite element method to analyze a troughed belt turnover. The purpose is to establish an analysis tool and propose an optimized troughed turnover design.

1. Introduction

Trough belt conveyor is a ubiquitous bulk material handling system. It is very efficient and reliable in transporting millions tons of bulk material, year over year. Typical arrangement has the material riding on a carry belt located at the top level of the conveyor structure. A return belt travels in the reverse direction at the lower level of the conveyor structure, beneath the carry belt, after the material is discharged. This arrangement simplifies the mechanical arrangement for material loading and unloading. But the work side, or the dirty side of the carry belt, is facing down during the return and in constant contact with return rolls. Residual material sticking to the dirty side of the belt, easily comes off from the belt and deposits on the ground or conveyor structure. This is called material carryback.

Modern, advanced belt cleaning system can do a very good job of cleaning the belt surface and minimizing material carryback. However, because a huge amount of material is being transported, even a tiny percentage of material carryback poses a serious problem over time. For example, if a conveyor transports 10 million tons of material in a year, a 0.001% material carry-back, a tiny percentage, amounts to 100 tons in a year. Cleaning the 100 tons from and beneath the conveyor is a difficult and expensive job. Without diligent cleaning, the material keeps piling up on the conveyor structure, reduces structural safety, and contaminates the bearings of rotating parts. The material also permeates into the environment, creates dust and affects human health.

The problem of dirty side facing down on the return belt, can be solved by adding a belt turnover. Typical belt turnover system uses pulleys or large rolls to guide the belt to rotate 180 degrees, so that the dirty side is now facing upward after the turnover. Certainly the conveyor can be arranged in a way that the return belt sits on the top and the carry belt sits on the bottom. Any material carryback deposits onto the carry belt. But complicated mechanical arrangement for proper material loading and unloading is required, which makes the solution uncompetitive in most cases.

2. Flat turnover – A Brief Review

In the flat turnover, the belt maintains more or less a straight line widthwise while making a helical turn of 180° lengthwise. Flat turnover typically uses three or five sets

of long rolls as guide rolls to enforce the straight belt cross section. There is one set of rolls or snub pulleys at the entrance of the belt turnover, one set at the exit. For the three-set arrangement, there is a vertical roll set in the middle of the turnover. For the five-set arrangement, there is one additional support rolls at 45° or quarter-length position, and one at 135° or three quarter-length position.

Flat turnover has been studied in detail (1,2). Both numerical and analytical tools have been developed to calculate:

- 1) Stress and belt safety factor across the belt width, along the length of the turnover;
- 2) Belt sag along the length of turnover.

These calculations are done with predefined belt rating, mass, tension and turnover length. The belt rating governs the belt modulus. Calculation tools that analyze flat belt turnovers are now part of competent conveyor design software like Beltstat. The designer can use the tool to determine the proper turnover length and arrangement.

In flat turnovers, the stress in belt edge is always higher than the stress in the center. This is because the belt edge travels a longer path than the center, which causes higher strain in the edge. The high edge stress needs to be checked against the allowable belt safety factor. The low center stress can even go into compressive condition and cause the belt to buckle. This may affect the service life of steel cords as they can only accommodate very limited amount of compressive stress.

Excessive belt sag is undesirable because the belt edge may scrape over ground or structure and be damaged. The maximum belt sag always occurs at the middle point of the belt turnover. Belt sag increases with lower belt tension and vice versa. A guide roll can be placed below the belt to limit any excessive sag during momentary, dynamic low tension condition. But it is a design goal to ensure that there is no excessive belt sag during steady state running.

For belt width less than 2000mm and belt rating less than ST5000N/mm, flat turnover usually is considered by the system designer. But for wider and higher strength belt, there is a concern that including the turnover would incur significant risk for the belt. Probably due to this reason, many high tonnage and high tension conveyor systems don't include turnover, even though the material carry-back from the high tonnage is more significant than low tonnage conveyors.

Another drawback of the flat turnover is the space requirement. At the center of the turnover, the belt is vertically flat. Additional space is needed for the vertical turnover rolls and clearance. In underground mining, space is expensive to create. If an underground conveyor uses a wide belt, there just isn't enough space to accommodate the flat turnover of a wide belt. On the other hand, cleaning material carry back is also more important but also more difficult for underground conveyors. As a result, if underground conveyors are to use belt turnover, a design with smaller profile is imperative.

3. Troughed Belt Turnover

Troughed belt turnover means the belt is not straight widthwise, but being formed into troughed or semi-circular shape by guide rollers during the turnover. The belt still makes the 180° helical turn lengthwise.

The perceived benefits of the troughed turnover, compared to the conventional flat turnover, include:

1. Reduced turnover length;
2. Less stress in the belt edge and less possibility of belt buckling in the center;
3. Less space requirement, suitable for underground application;

Walter Mordstein pioneered the concept of troughed belt turnover in 1960s. Figure 1 shows the schematic of the Mordstein turnover in the related US patent (3). The Mordstein turnover uses a series of sphere-shaped guide rolls that are positioned around a center axis to guide and support the belt. The axial position, the angle and the arm length of each guide roller can be adjusted. The intention is to give maximal flexibility so that the Mordstein turnover can accommodate a wide variety of belts and tension conditions. In reality, conveyor operators are often confounded by the vast degree of freedom of the adjustment. It is difficult to find an optimal roll arrangement, especially if the belt tension has large fluctuation during operation.

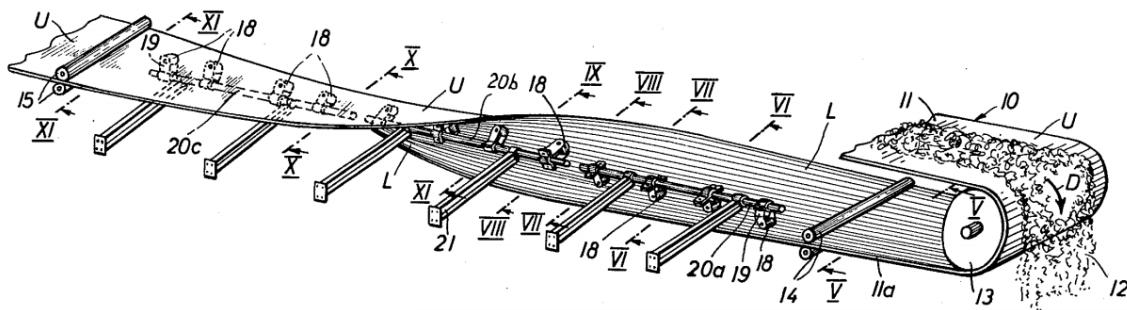


Figure 1, Mordstein Turnover Schematic

The author noticed there have been a wide range of design approaches to the troughed turnover. Different practitioners have different philosophies on the guide roll design, arrangement and turnover length. Analysis, design tools and literature are very rare.

4. Troughed Belt Turnover Analysis

In this study, an optimized troughed turnover is proposed. The turnover design is based on a steel cord belt with the parameters shown in Table 1. The author felt that this would be a typical scenario where system designers start to have concerns about implementing a belt turnover system.

Table 1, Parameters of the Belt and Turnover in this Study

Belt Width	2000mm	Steel Cord Pitch	19.5mm
Belt Strength	ST-5200	Cover Thickness	10×8
Cord Diameter	11mm	Belt Weight	109 kg/m
Steel Cord Break Tension	104kN	Number of Steel Cords	100
Steel Cord Ultimate Stress	1094MPa	Belt Modulus	372537 kN/m

Flat turnover Length	48m (24 × Belt Width)	Belt Tension at Turnover	Belt Safety Factor 25 (416 kN)
Troughed Turnover Length	36m (18 × Belt Width)		

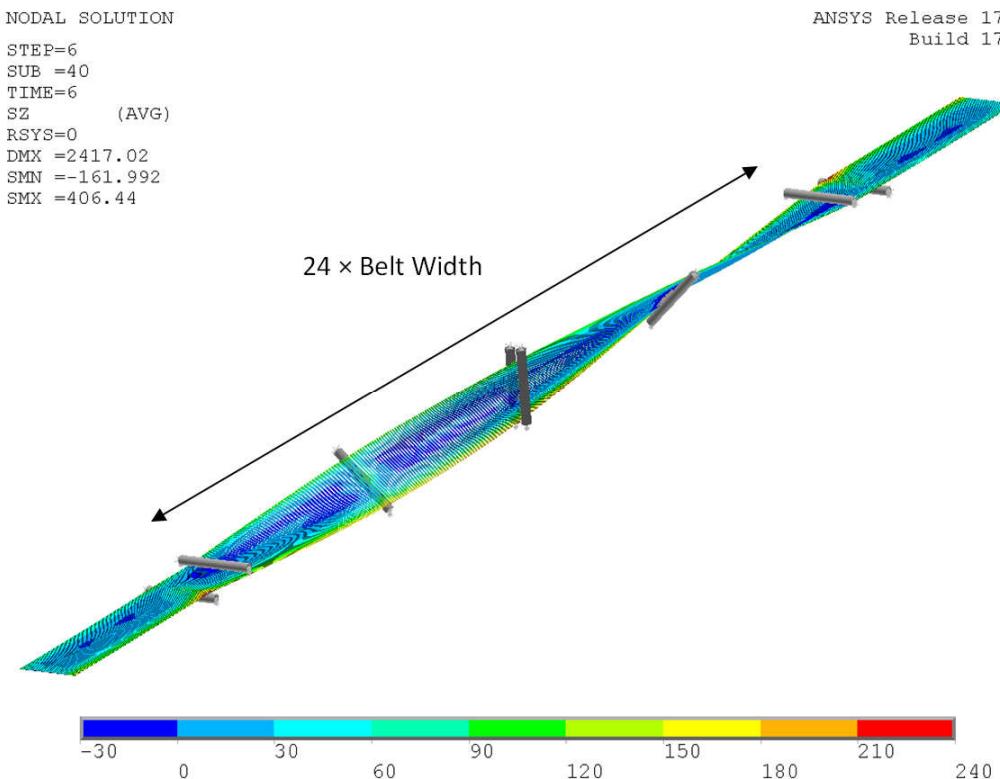


Figure 2, Flat Turnover Model showing the Tensile Stress in Steel Cords

Finite element analysis (FEA) in Ansys software is done on a flat turnover and a troughed turnover, with the same belt specification and belt tension. The turnover length is different in two models. The finite element model of the belt includes individual steel cords and cover rubber, instead of using homogeneous shell elements for the whole belt. This approach increases the model size and calculation time but improves accuracy. Belt sag, stress in steel cords, the overall belt shape are compared between the flat turnover and the troughed turnover. The flat turnover is mainly used as the benchmark to evaluate against the troughed turnover. Figure 2 shows the flat turnover and the tensile stress in the steel cords. The turnover length is $24 \times$ (belt width) or 48m. Figure 3 shows the center part of the flat turnover. The cover rubber is not shown in the two figures. The tensile stress is higher in the belt bottom than the belt edge, due to the belt sag by gravity. The maximal stress is around 190MPa, or 5.64 belt safety factor. Such results are close to what the turnover analysis in the Beltstat software is showing.

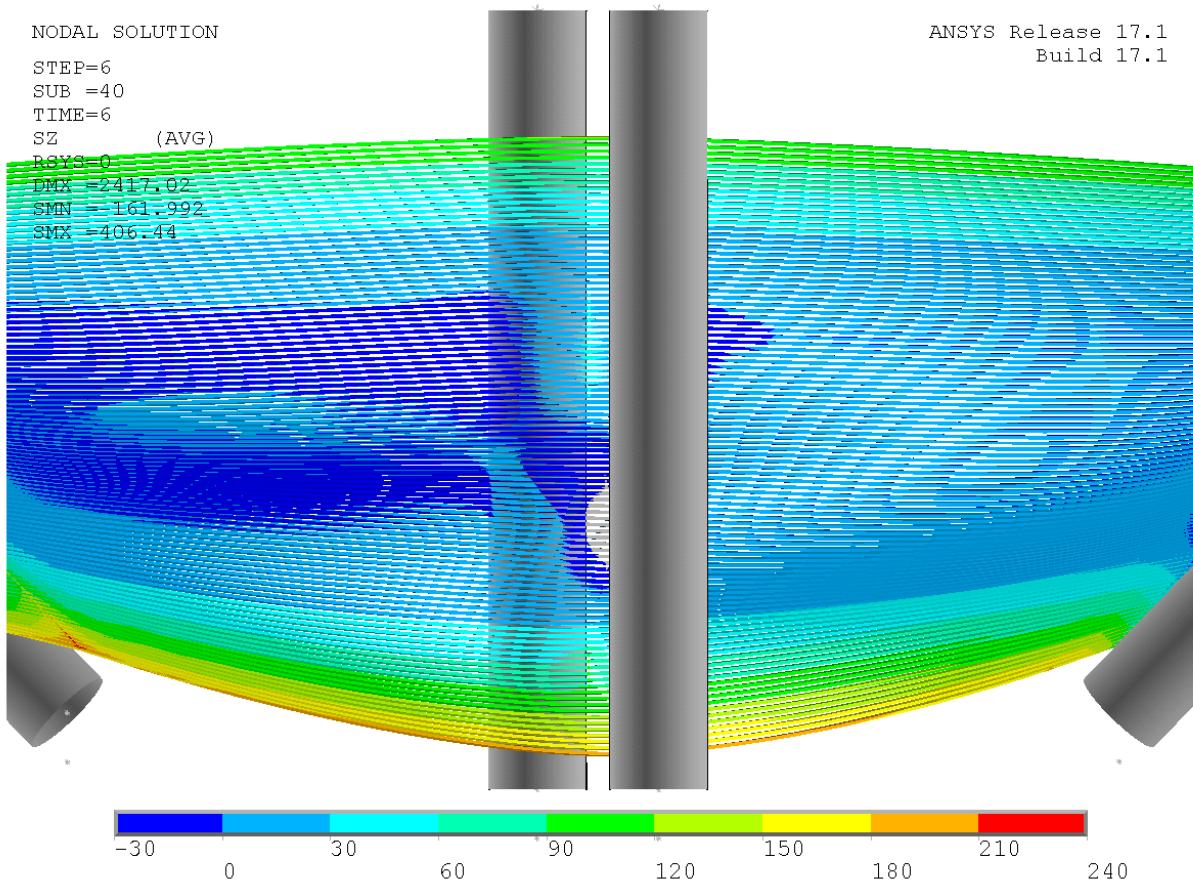


Figure 3, Tensile Stress in Flat turnover at the center of the flat turnover.

Multiple troughed turnover arrangements were attempted during the study, and the arrangement presented in this paper has the best results among them. Figure 4 and Figure 5 show the troughed turnover model and tensile stress in steel cords. The turnover length is $18 \times$ belt width or 36m, shorter than the comparable flat turnover. This turnover design has the following advantages:

1. Use trough rolls as guide rolls, instead of finger rolls or spherical rolls, to minimize cover wear
2. Minimal adjustment is needed after installation; turnover arrangement is analyzed and optimized during design phase;
3. Belt in trough shape at one end of the turnover and in flat shape at the other end, reducing the turnover length and simplifying pulley arrangement.
4. Turnover profile and length are reduced compared to flat turnover.
5. Stress in Belt is improved compared to the flat turnover.

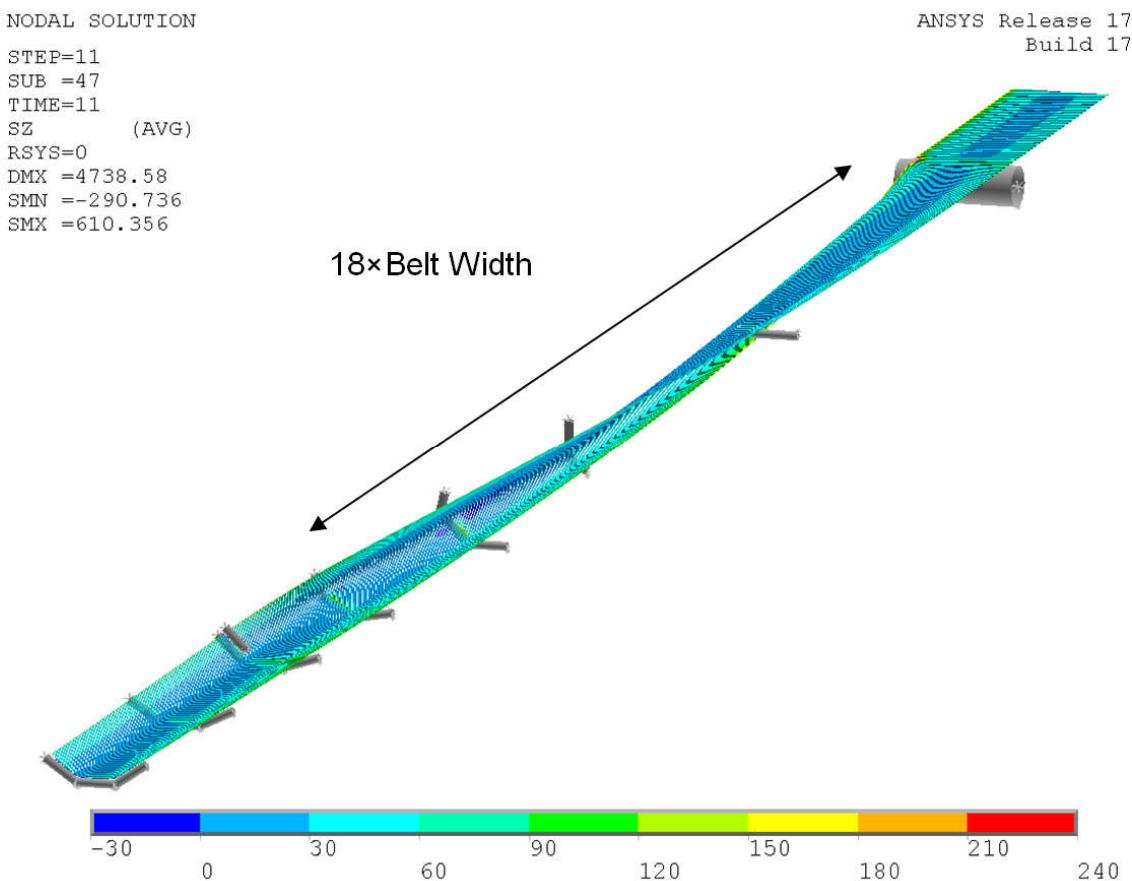


Figure 4, Troughed Turnover Model showing the Tensile Stress in Steel Cords

Consideration on Guide Rolls

There are many types and arrangements of guide rolls for troughed turnovers. The purpose of guide rolls is to support the belt turnover and limit uncontrolled belt displacement. The Mordstein turnover uses spherical rolls as guide rolls. Finger rolls with spherical heads are also used. The spherical roll rotates around a single axis; every point on the roll surface rotates around the axis at the same angular velocity. Because the radius from the surface to the axis varies, the line velocity at the surface is not constant. As a result, when the spherical guide rolls contact the belt surface, there is sliding contact because the belt moves only at a single line velocity. The sliding contact between steel and rubber causes excessive wear in the cover rubber, and should be minimized it.

In the proposed troughed turnover design, ordinary cylindrical rolls are used as guide rolls. The line velocity on the cylindrical surface is constant, so rolling contact with the belt is maximized and sliding contact is minimized. Cylindrical idler rolls are also less expensive and more readily available. The cylindrical guide rolls support the belt

from the pulley cover or bottom cover of the belt. Only two finger rolls with spherical heads are used, and the spherical heads normally are not in contact with the belt. One finger roll is placed after a snub pulley to support the belt and reduce belt sag. A second finger roll is a hold down roll positioned above the belt to prevent belt lift.

Consideration on Adjustments

Flat turnover is popular because it is simple, straight forward and requiring no adjustment. One problem of the troughed turnover has been that there is too much degree of freedom for guide roll adjustment. The proposed turnover design needs minimal adjustment. Only the finger roll after the snub pulley may need small adjustment to prevent the spherical head being in constant contact with the belt. The optimal guide roll location and shape are analyzed in the design phase through FEA to achieve an optimal arrangement. This approach simplifies the maintenance and ease of use of the troughed turnover.

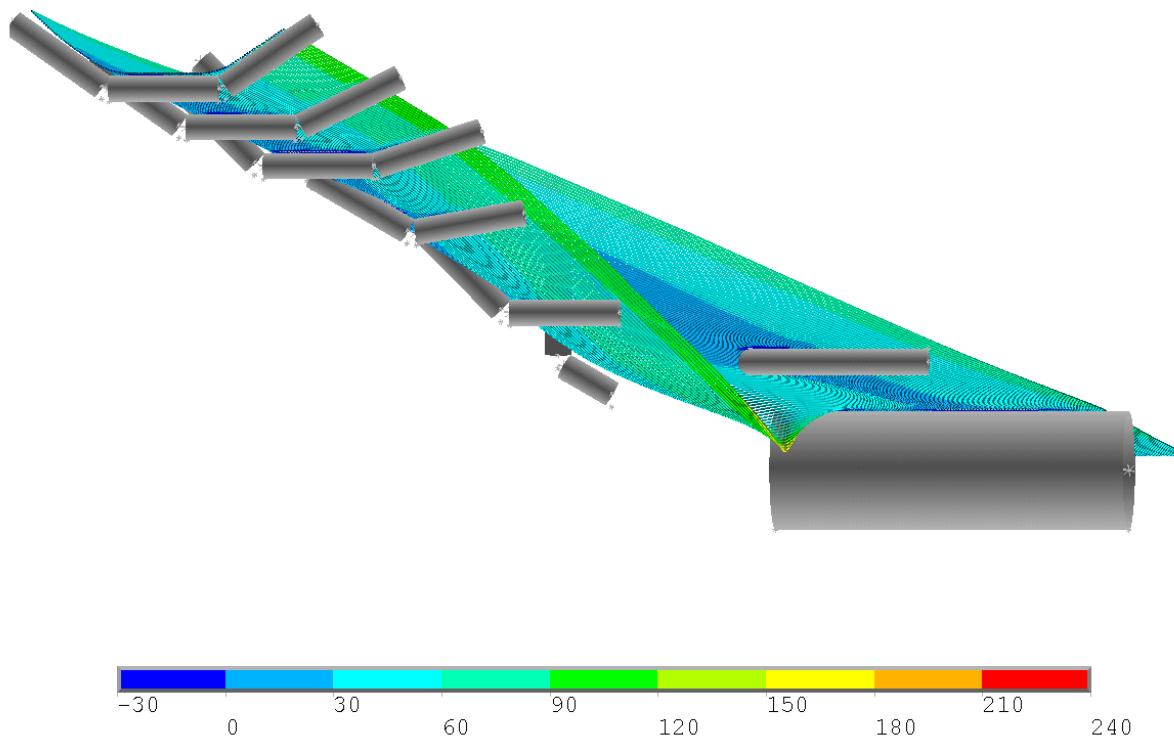


Figure 5, Troughed Turnover Model showing the Tensile Stress in Steel Cords, Viewing from Different Direction

Belt Shape at the Ends of Turnover

In the proposed design, the belt is in troughed shape at one end of the turnover and in flat shape at the other end. This approach reduces the turnover length and snub pulleys.

If the turnover is located at the discharging or head end of the conveyor, the belt enters the turnover in flat shape, after leaving bend or drive pulleys. The belt curls into a semi-circular shape before the mid-point of the turnover, lands on to trough roll sets, and then moves onto to regular return V or trough rolls. No additional belt transition is necessary after the turnover.

If the turnover is located at the loading or tail end of the conveyor, the belt enters the turnover in troughed shape, after leaving return trough or V rolls. At the exit of the turnover, the belt goes over a snub pulley that enforces the flat belt shape, and then goes into tail pulleys.

Small Turnover Profile and Shorter Length

The vertical turnover profile is significantly reduced compared to the flat turnover. The 2m wide belt in a flat turnover stands at 2m vertically at the center of turnover. Figure 6 shows the vertical displacement of the troughed turnover of the same 2m wide belt. Here the vertical profile is only 1130mm (258mm+872mm), almost half space compared to the flat turnover. It is reasonable to expect that for belts with different specifications, troughed belt turnover can achieve a vertical profile around half of the belt width, excluding the clearance for guide rolls and structures. Another advantage of the troughed turnover in reducing the vertical profile is that the belt center line can be lowered during the turnover, so that the top edge of the belt sits at a lower position. This will further reduce space requirement and help the turnover arrangement in underground applications. Lowering belt center line is more difficult to do in the flat turnover, because the lower belt edge will have much higher increases in stress.

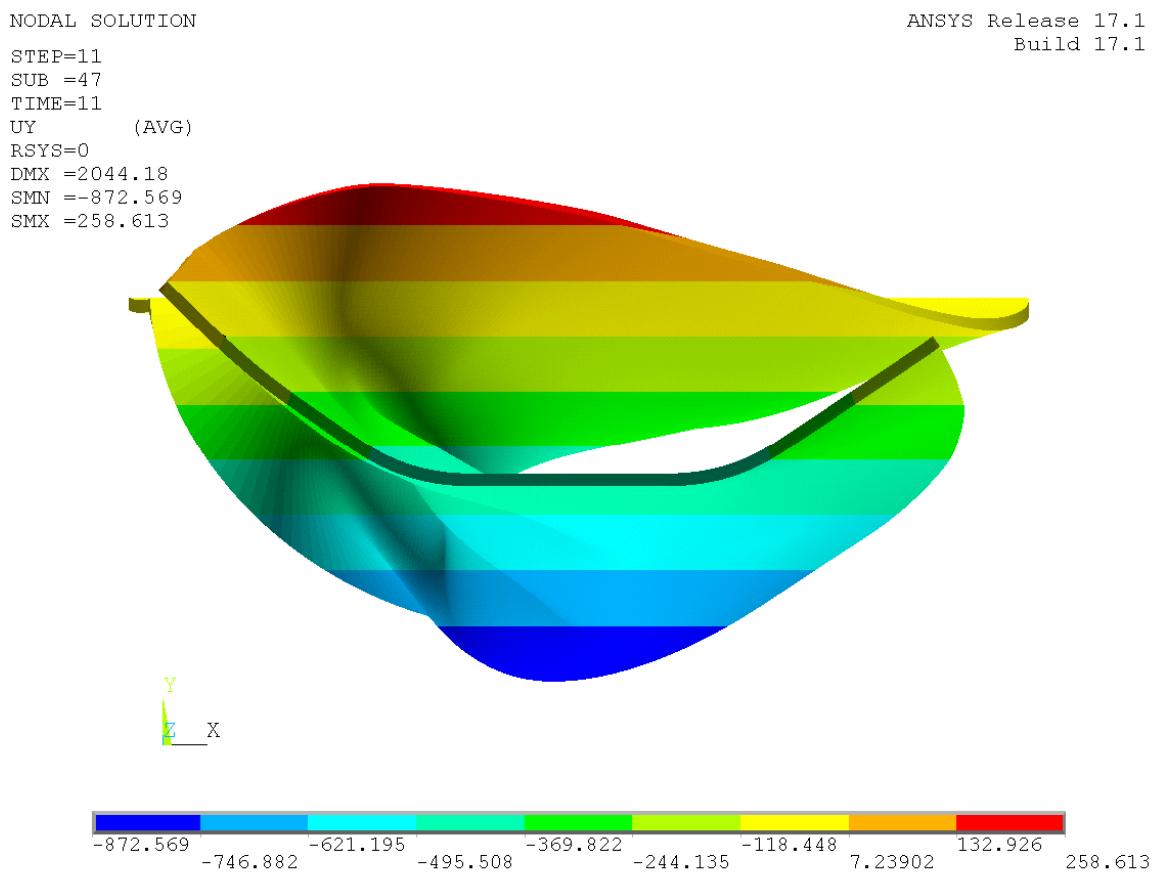


Figure 6, Vertical Displacement of the Troughed Turnover, Viewing from the Belt Center Line

The troughed turnover has shorter length. In the current analysis, the turnover is $18 \times$ Belt Width, compared to the flat turnover of the same belt over a distance of $24 \times$ Belt Width. The reduction in turnover length is 25%. Shorter turnover length is always welcomed by conveyor system designers to achieve a more economic design.

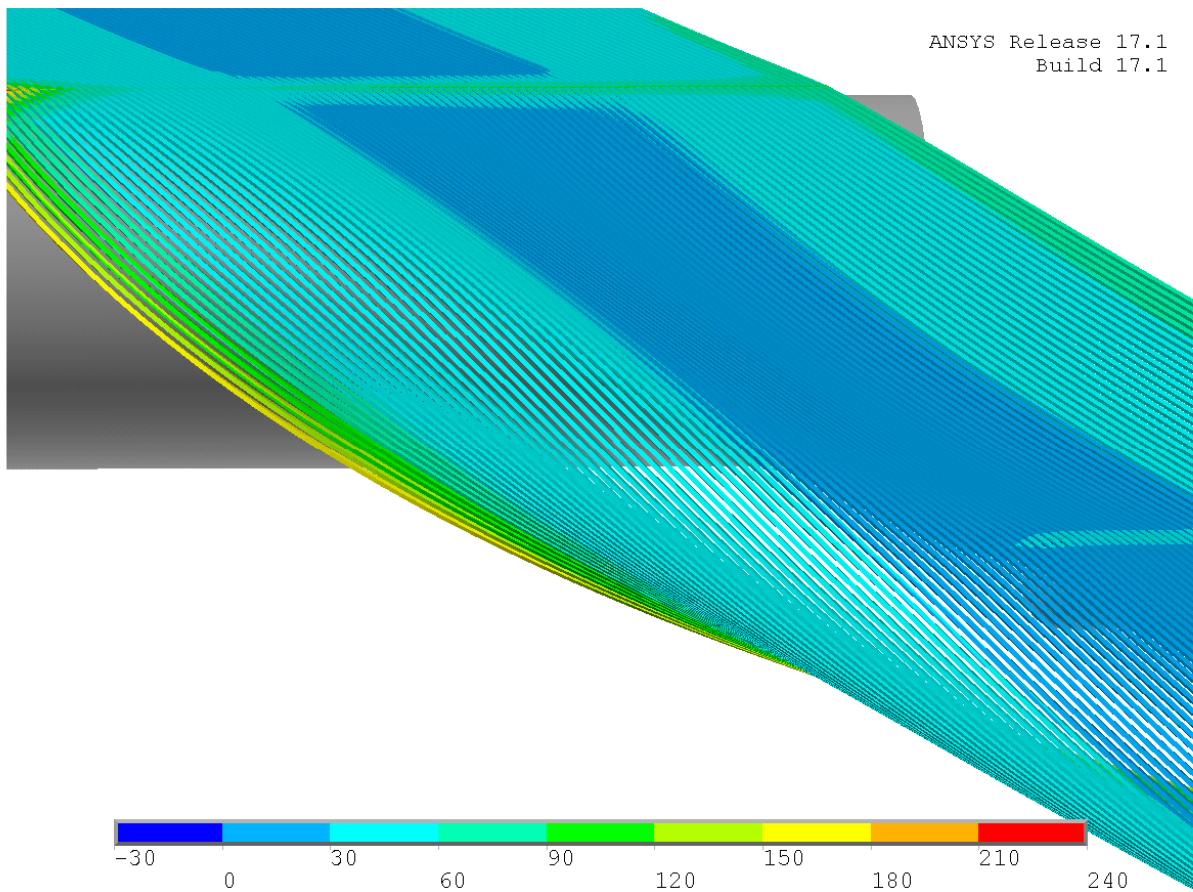


Figure 7, Tensile Stress in Steel Cords in Troughed Turnover, after the Snub Pulley Region

Stress in the Belt

During the troughed turnover, the travel length of the belt edge is reduced, thus reducing the belt edge stress. The travel length of the center is increasing, thus reducing the compressive stress in the belt center. Comparing Figure 3 and Figure 7, the maximum belt edge stress in the troughed turnover is 16.7% lower than that in the flat turnover, even the troughed turnover is 25% shorter than the flat turnover. The stress in the belt center, which tends to go compressive, is higher in the troughed turnover than the flat turnover Figure 3 and Figure 7. This helps prevent belt buckling.

5. Conclusion

By comparing a flat turnover and troughed turnover using the same 2m wide ST-5200 belt under same tension, it is found that the troughed turnover can have lower belt edge stress and higher belt center stress, while the troughed turnover is 25% shorter. The troughed turnover needs smaller vertical space as well. The belt in troughed turnover is 56% in height compared to the flat turnover. This troughed turnover is

accomplished by using multiple trough roll sets as guide rolls, with minimal finger rolls, so that belt cover wear is minimized. The guide rolls require almost no adjustment during the operation. The belt is in troughed shape at one end of the turnover and in flat shape at the other end. This simplifies idler and pulley arrangements. This numerical tool based on finite element analysis can also be used to analyze and improve other troughed turnover designs.

Reference

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