A FINITE ELEMENT ANALYSIS ON THE TROUGHED BELT TURNOVER

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ABSTRACT

A belt turnover is an effective way to reduce material carry-back on the return side. It has the ability to reduce environmental contamination and maintenance work, and improves return idler roll life. Flat turnover has been the dominant belt turnover method to date. For extra wide and high strength belts, the concern is that the flat turnover requires long length, large space, and causes high sag and stress in the belt.

A troughed belt turnover, pioneered by the Mordstein[3] 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 is 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 analyse a troughed belt turnover. The purpose is to establish an analysis tool and propose an optimised troughed turnover design.

1. INTRODUCTION

A troughed belt conveyor is an ubiquitous bulk materials handling system. It is very efficient and reliable in transporting millions of tonnes of bulk material, year after year. A typical arrangement has the material riding on a carry belt located at the top level of the conveyor structure. After the material has been discharged, a return belt travels in the reverse direction at the lower level of the conveyor structure, beneath the carry belt. This arrangement simplifies the mechanical arrangement for material loading and unloading. But the work side, or the dirty side of the carry belt, faces down during the return and is in constant contact with return rolls. Residual material sticking to the dirty side of the belt easily comes off and is deposited on the ground or conveyor structure. This is called material carry-back.

Modern, advanced belt cleaning systems can do a very good job of cleaning the belt surface and minimising material carry-back. However, because a huge amount of material is being transported, even a tiny percentage of material carry-back poses a serious problem over time. For example, if a conveyor transports 10 million tonnes of material in a year, a 0.001% material carry-back, a tiny percentage, amounts to 100 tonnes in a year. Cleaning the 100 tonnes from and underneath the conveyor is a difficult and expensive job. Without diligent cleaning, the material keeps piling up on the conveyor structure, reducing 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. The conveyor belt can be arranged in a way that the return belt sits on the top and the carry belt sits on the bottom. As a result, the material carry-back deposits onto the carry belt. But it involves a complicated mechanical arrangement for material loading and unloading, which makes this solution uncompetitive.

2. FLAT TURNOVER – A BRIEF REVIEW

In the flat turnover, the belt maintains more or less a straight line width-wise, while making a helical turn of 180° length-wise. A flat turnover typically uses three or five sets of long rolls as guide rolls to maintain the straight belt cross-section. There is one set of rolls or snub pulleys at the entrance of the belt turnover and one set at the exit. In 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 roll at 45° or quarter-length position, and one at 135° or three-quarter-length position.

A flat turnover has been studied in detail[1,2]. Both numerical and analytical tools have been developed to calculate:

1. Stress and belt safety factors 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 analyse flat belt turnovers are now part of competent conveyor design software. The designer can calculate the proper turnover length and arrangement.

In flat turnovers, the stress in belt edge is always higher than the stress in the centre. This is because the belt edge travels a longer path than the centre, which causes higher strain in the edge. The high edge stress needs to be checked against the allowable belt safety factor. The low centre 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 amounts of compressive stress.

Excessive belt sag is undesirable because the belt edge may scrape over the ground or the 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 a 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 a belt width less than 2 000 mm and belt rating less than St5000 N/mm, flat turnover usually is considered by the system designer. But for wider and higher strength belts, 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 turnovers, 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 centre 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 a smaller profile is imperative.

3. ROUGHED BELT TURNOVER

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

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 centre
3. Less space requirement, suitable for underground application.

Walter Mordstein pioneered the concept of troughed belt turnover in 1960s. Figure 1**Error! Reference source not found.** 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 centre 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 fluctuations during operation.

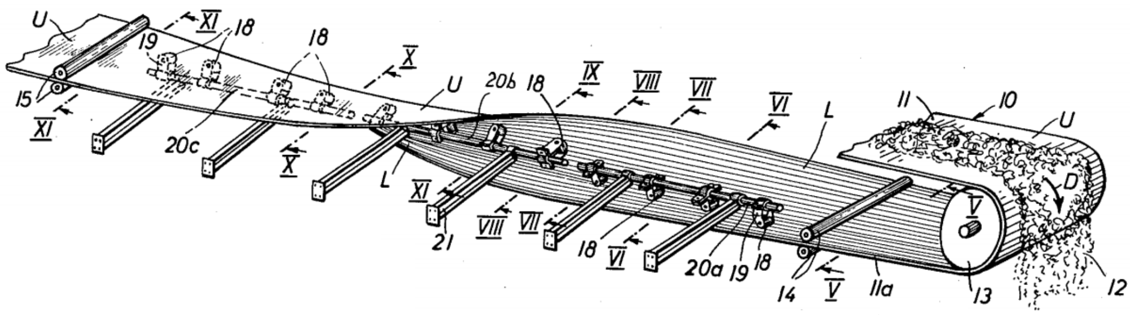

Figure 1. Mordstein turnover schematic.

It was noticed there had 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. Analyses, design tools and literature are very rare.

4. TROUGHED BELT TURNOVER ANALYSIS

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

Belt Width	2000 mm	**Steel Cord Pitch**	19.5 mm
Belt Strength	ST-5200	**Cover Thickness**	10×8
Cord Diameter	11 mm	**Belt Weight**	109 kg/m
Steel Cord Break Tension	104kN	**Number of Steel Cords**	100
Steel Cord Ultimate Stress	1094 MPa	**Belt Modulus**	372537 kN/m
Flat Turnover Length	48 m (24 × Belt Width)	**Belt Tension at Turnover**	Belt Safety Factor 25 (416 kN)
Troughed Turnover Length	36 m (18 × Belt Width)		

Table 1. Parameters of the belt and turnover in this study.

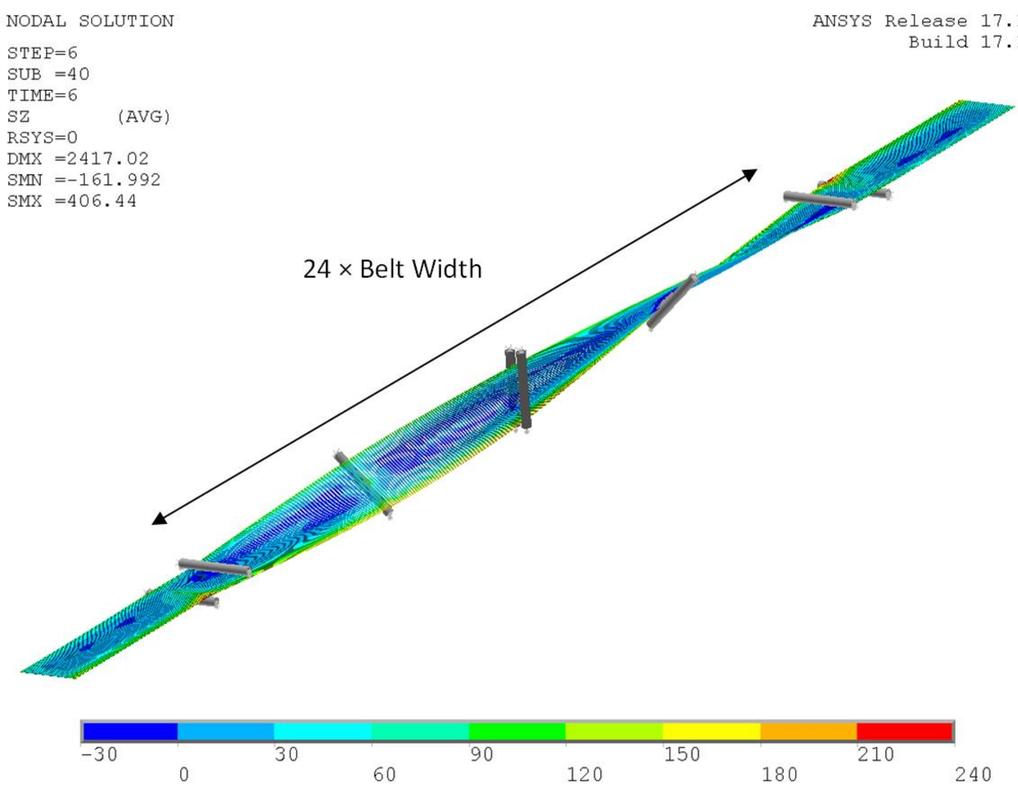

Figure 2. Flat turnover model showing the tensile stress in steel cords.

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 and 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 × (belt width) or 48 m. Figure 3 shows the centre of the flat turnover. The cover rubber is not shown in the two figures. The tensile stress is higher along the belt bottom edge than the belt top edge, due to the belt sag by gravity. The maximal stress is around 190 MPa, or 5.64 belt safety factor.

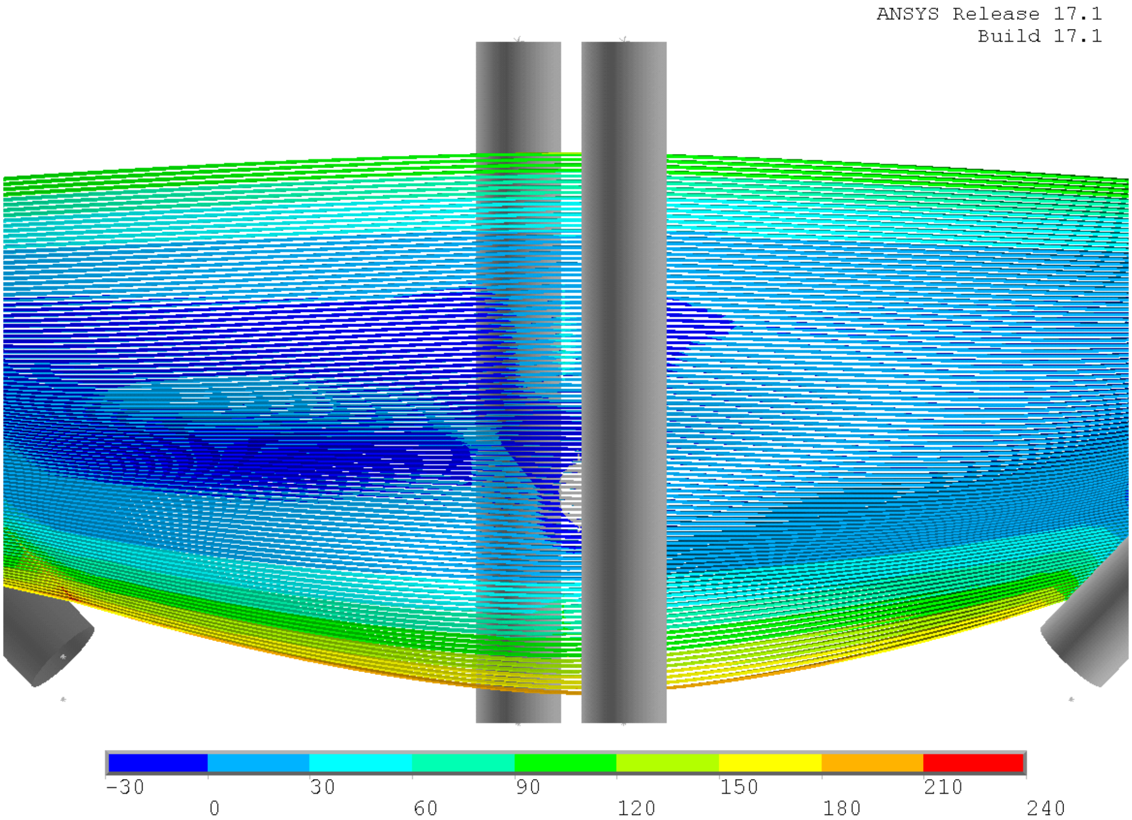

Figure 3. Tensile stress in flat turnover at the centre of the flat turnover.

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

1. Uses trough rolls as guide rolls, instead of finger rolls or spherical rolls, to minimise cover wear
2. Minimal adjustment is needed after installation; turnover arrangement is analysed and optimised during the design phase

3. Belt is 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.

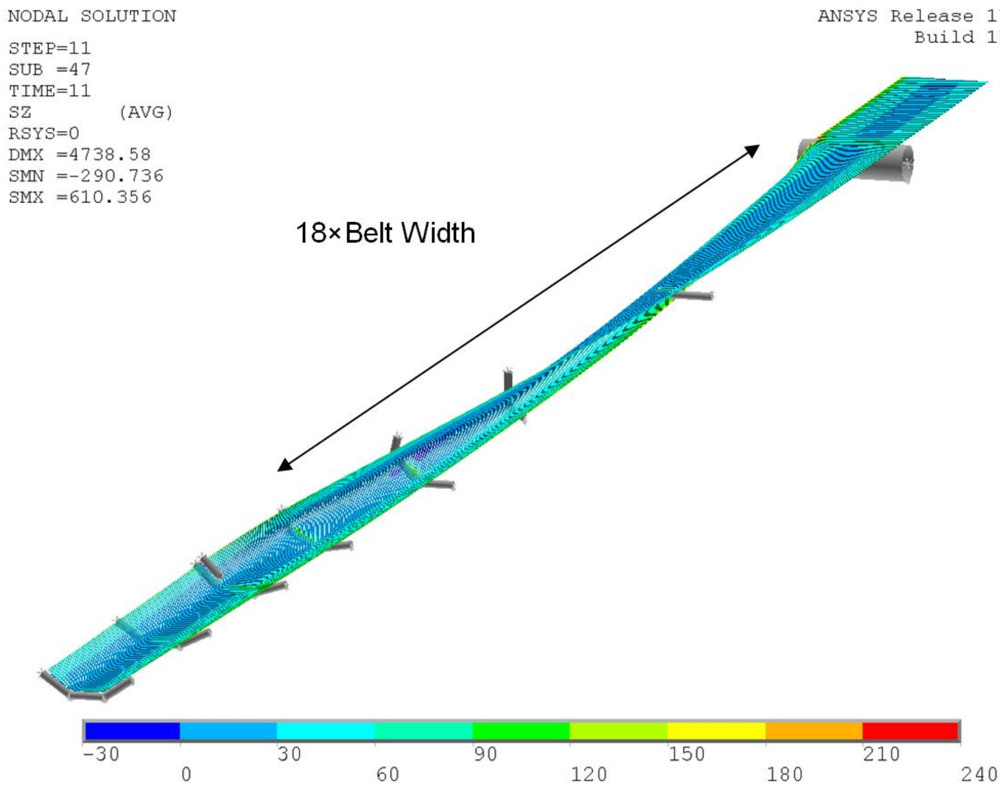

Figure 4. Troughed turnover model showing the tensile stress in steel cords.

CONSIDERATION OF 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 minimised.

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 maximised and sliding contact is minimised. 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 are normally 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 OF ADJUSTMENTS

Flat turnover is popular because it is simple, straightforward and requires no adjustment. One problem of the troughed turnover has been that there is too big a 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 adjustments to prevent the spherical head from being in constant contact with the belt. The optimal guide roll location and shape are analysed in the design phase using FEA to achieve an optimal arrangement. This approach simplifies the maintenance and ease of use of the troughed turnover.

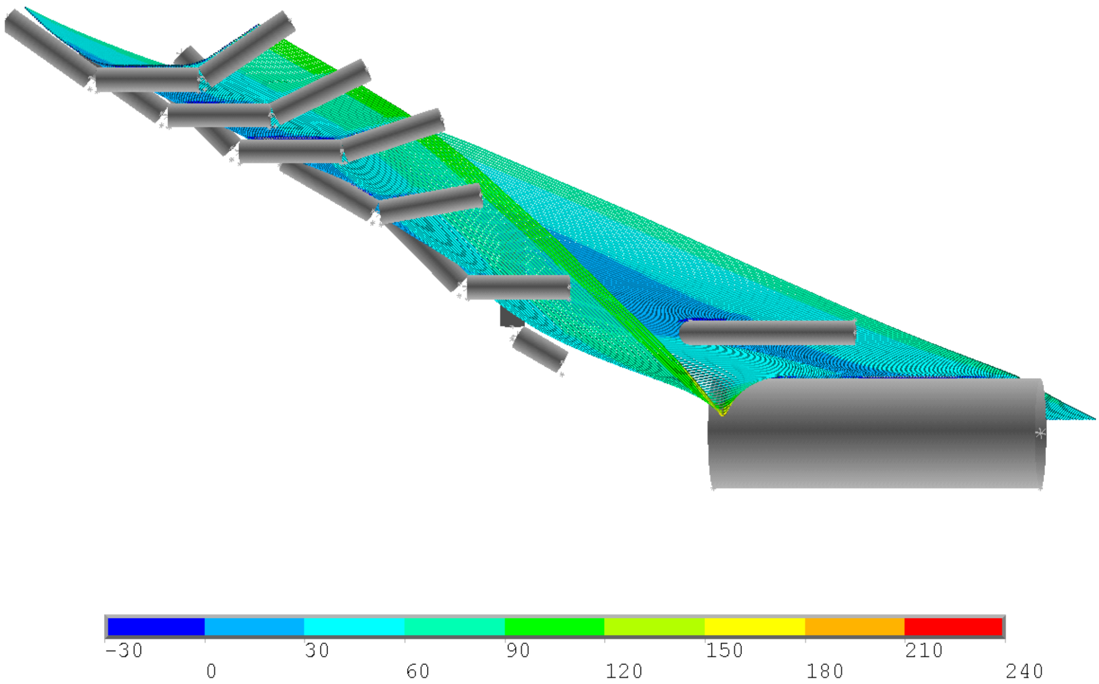

Figure 5. Troughed turnover model showing the tensile stress in steel cords, viewed from a different direction.

BELT SHAPE AT THE ENDS OF THE 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 the bend or drive pulleys. The belt curls into a semi-circular shape before the mid-point of the turnover, lands onto 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 the 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 2 m wide belt in a flat turnover stands at 2 m vertically at the centre of turnover. Figure 6 shows the vertical displacement of the troughed turnover of the same 2 m- wide belt. Here the vertical profile is only 1 130 mm (258 mm+872 mm), almost half the 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 centre line can be lowered during the turnover, so that the top edge of the belt sits at a lower position. This further reduces space requirements and helps the turnover arrangement in underground applications. Lowering the belt centre line is more difficult to do in the flat turnover, because the lower belt edge will have much higher increases in stress.

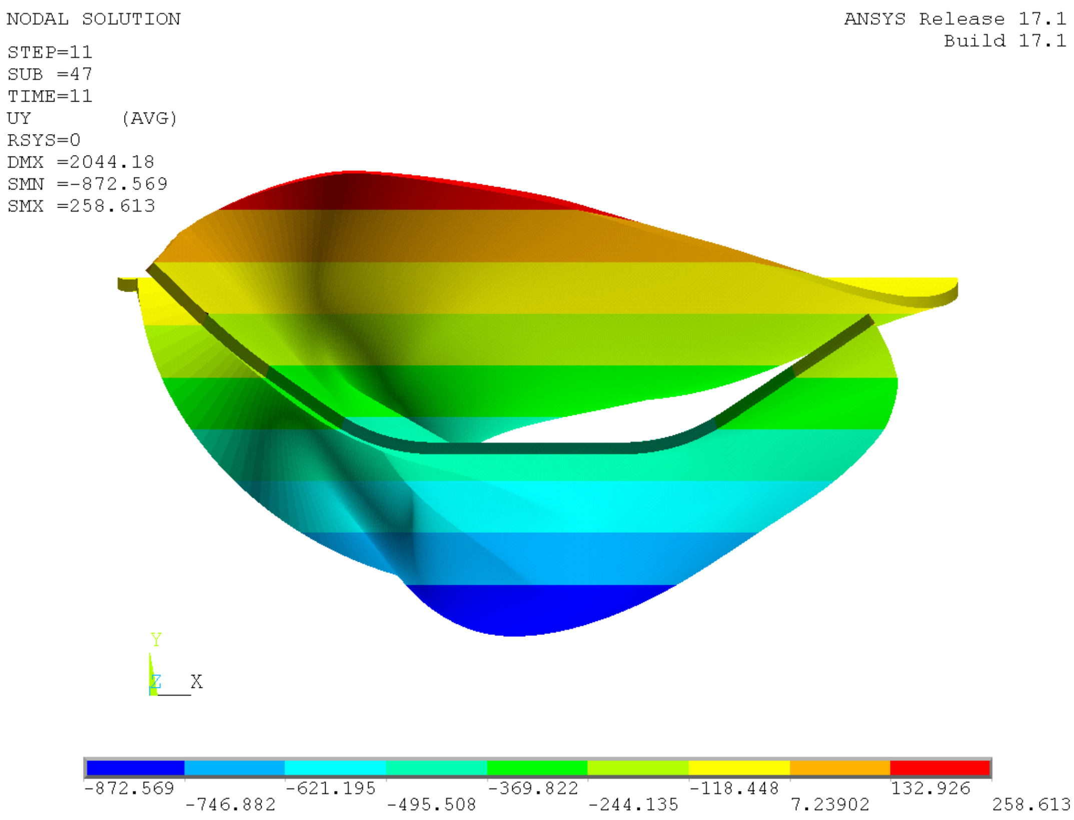

Figure 6. Vertical displacement of the troughed turnover, viewed from the belt centre line.

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

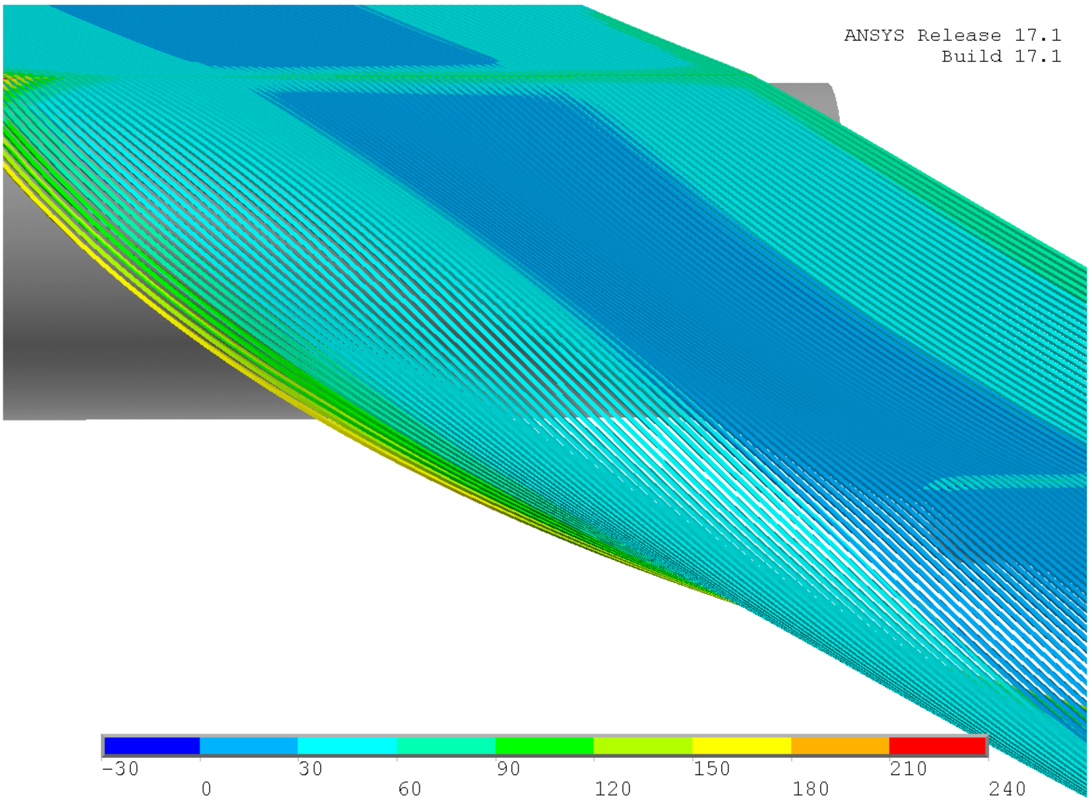

Figure 7. Tensile stress in steel cords in troughed turnover, after the snub pulley region.

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 centre increases, thus reducing the compressive stress in the belt centre. Comparing Figure 3 with Figure 7, the maximum belt edge stress in the troughed turnover is 16.7% lower than that in the flat turnover, even with the troughed turnover being 25% shorter than the flat turnover. The stress in the belt centre, which tends to go compressive, is higher in the troughed turnover than the flat turnover. This helps prevent belt buckling.

5. CONCLUSION

By comparing a flat turnover and troughed turnover using the same 2 m wide ST-5200 belt under the same tension, it was found that the troughed turnover can have lower belt edge stress and higher belt centre 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 minimised. The guide rolls require almost no adjustment during 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 analyse and improve other troughed turnover designs.

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Dr Yijun Zhang obtained his Ph.D in materials science and engineering from Michigan State University in 2006. He started working at Conveyor Dynamics Inc. in 2007 and currently is the technical director and a member of the board of directors of CDI. He has been a licensed professional engineer in Washington State since 2011. Dr Zhang has designed and audited over 60 km currently operating trough and pipe conveyors, and assisted with the belt design and system review for over 100 km of patented pipe belting, of which he is a co-inventor. He also invented the cable bridge conveyor, a suspension bridge based conveyor system with a long span between support points.

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