# DESIGN OF SAFE BELT SPLICES

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## INTRODUCTION

When a conveyor belt breaks, all energy within the conveyor system is instantaneously released. The belt rapidly returns to its original length and accelerates down slopes. Belt ends flap uncontrollably as they rush along the conveyor. The result is a potentially very dangerous situation in which the conveyor structure and anything in the path of the belt can be destroyed.

This paper describes the procedures that should be followed in design of conveyor belt splices. Conveyor belting is manufactured in three basic constructions. The three basic belt conveyor belt constructions are:

1. Cord construction
2. Multi-ply woven textile construction
3. Solid woven construction.

The principles of design are essentially the same for all belt constructions.

The main characteristics of the three constructions are described in this paper, thus providing an understanding of the need for different types of splice design.

Limitations in the manufacturing process, transport, storage and belt installation mean that virtually every conveyor belt has at least one join. A very few highly specialised types of belt conveyor, such as a flinger conveyor, use a truly endless belt in which there is no join. The success of belt conveyor systems is therefore dependent on achieving a reliable belt joining method that can be undertaken with consistent results under a wide range of conditions. It is important that the join has properties that closely match those of the conveyor belt itself.

## PRINCIPLES OF GOOD BELT SPLICE DESIGN

The belt properties of the join should match as closely as possible the properties of the belt itself. The most important matched properties are thickness, stiffness, strength and width.

Conveyor belting is constructed of a carcass protected by covers. The carcass is made up of longitudinal strength-carrying members and optional lateral binding, stiffening or performance enhancing elements. Commonly used belt carcass materials are cotton, polyamide, polyester and steel. Other, less common materials are glass and para-aramid.

Belt carcass constructions in common use are cord, multi-ply, solid woven and straight warp. In general each of these constructions require a different splice design. If the splice area has physical properties that match or improve upon the properties of the belt, then the splice will last the lifetime of the belt.

**MULTI-PLY CARCASS CONSTRUCTION**

Multiple layers (plies) of woven fabric are held together with rubber interlayers as shown in Figure 1.

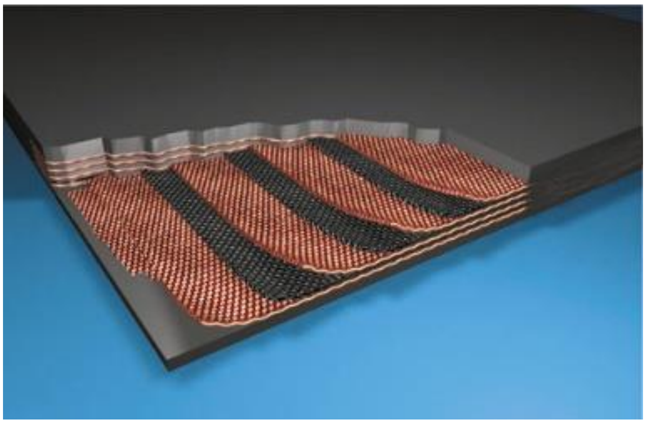

Figure 1. Multi-ply construction

A magnified side view representation of a three-ply carcass construction is shown in Figure 2.

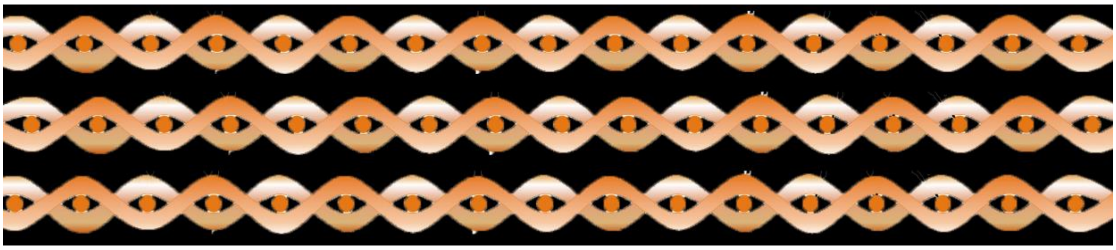

Figure 2. Enlarged side view of three-ply carcass

The multi-ply belting is joined by a stepped splice. Each end to be joined together is stepped back, the inter-ply rubber replaced and the two sides then overlapped as depicted below.

Figure 3. Stepped splice side view

In designing the splice, the forces to separate the two ends must be known. The two ends are held together by the inter-ply rubber. The resistance to separation is a function of the shear strength of the inter-ply rubber and the adhesion to the carcass. In order to design the splice, the properties of the rubber inter-ply must be known. A series of tests are carried out to establish the force per unit of length to pull apart two ends of belt joined by a given thickness of rubber.

Figure 4. Apparatus to measure separation force

Results typical of those shown in Figure 5 are obtained when a series of tests at differing lengths are carried out. In this particular example three different thicknesses of the same rubber were used.

When the test samples have good adhesion to the prepared surface, the results of force required to shear a 10 mm wide sample should be consistent for those in which the overlapped (joined) lengths are the same. The graph indicates a linear relationship between the overlap length and the force to separate, except in the case of overlap length less than 20 mm. For the example shown, the separation force is 0.74 N/mm$^2$ for 0.4 mm inter-ply rubber, 0.85 N/mm$^2$ for 0.8 mm and 0.90 N/mm$^2$ for 1 mm inter-ply rubber. The splice should be designed such that the force to separate the two ends spliced together are equal to the belt breaking strength.

That is

$$L_s = \frac{T_b}{\tau_t}$$

Where

$L_s$ = Splice overlap length
$T_b$ = Belt class
$\tau_t$ = Separation force for the relevant rubber thickness

The thickness of inter-ply rubber used in the splice should ensure that the spliced belt thickness matches the original belt thickness. This means that the inter-ply rubber thickness in the splice must be same as in the original belt. The inter-ply thickness can vary between 0.4 mm and 1.0 mm. The belt breaking strength is equal to the class.

So, if a 0.4 mm inter-ply rubber is used to splice a class 500/3 belt and the tested rubber shear strength properties are as given in Figure 5, then the overlap length of the splice must be:

$$L_s = \frac{500}{0.74} = 676 \text{ mm}$$

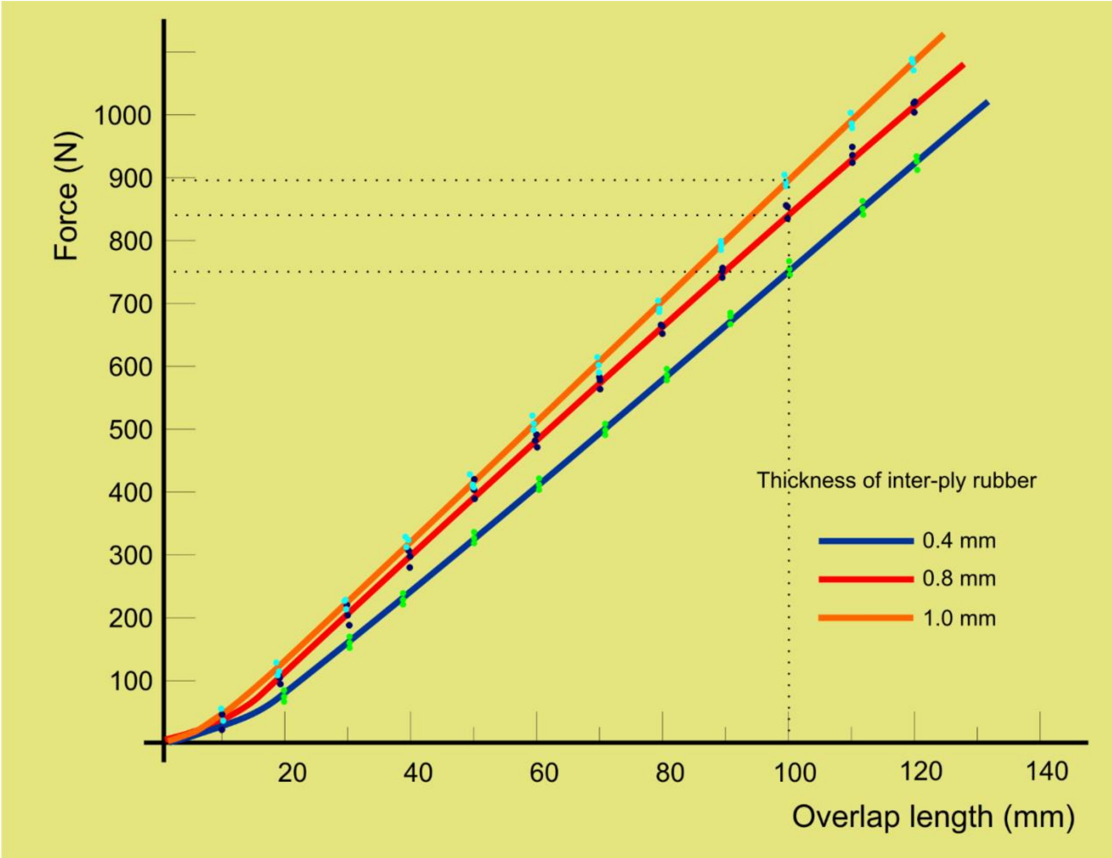


Figure 5. Force to separate joined belt ends vs length

The side view of a stepped splice shown in Figure 3 depicts a three-ply belt. It is seen that a stepped join in a three-ply belt has two steps. This arrangement ensures that the number of plies in the splice remain the same as those in the belt and it follows that the number of steps in a stepped splice is always one less than the number of plies. For maximum efficiency (shortest overall splice length), the step lengths must be equal. Therefore, in the example above (using 0.4 mm thick inter-ply rubber) the splice should be made with two steps each of 338 mm in length. At both ends of the splice a short junction area is created so that the join in the original rubber cover and the outer ply do not coincide. This junction, often referred to as the bridge, is of nominal 30 mm to 50 mm length. A full splice layout diagram for the example splice is shown in Figure 6. In the plan view the two ends are offset only for purposes of clarity. The centre lines drawn on each belt end must meet and remain on the combined centre line through the splice. Likewise the side view has the two ends separated for purposes of clarity only. The top half of the splice would be in contact with the inter-ply rubber and hence overall thickness in the join matches the original belt thickness provided the original belt had 0.4 mm thick inter-ply rubber.

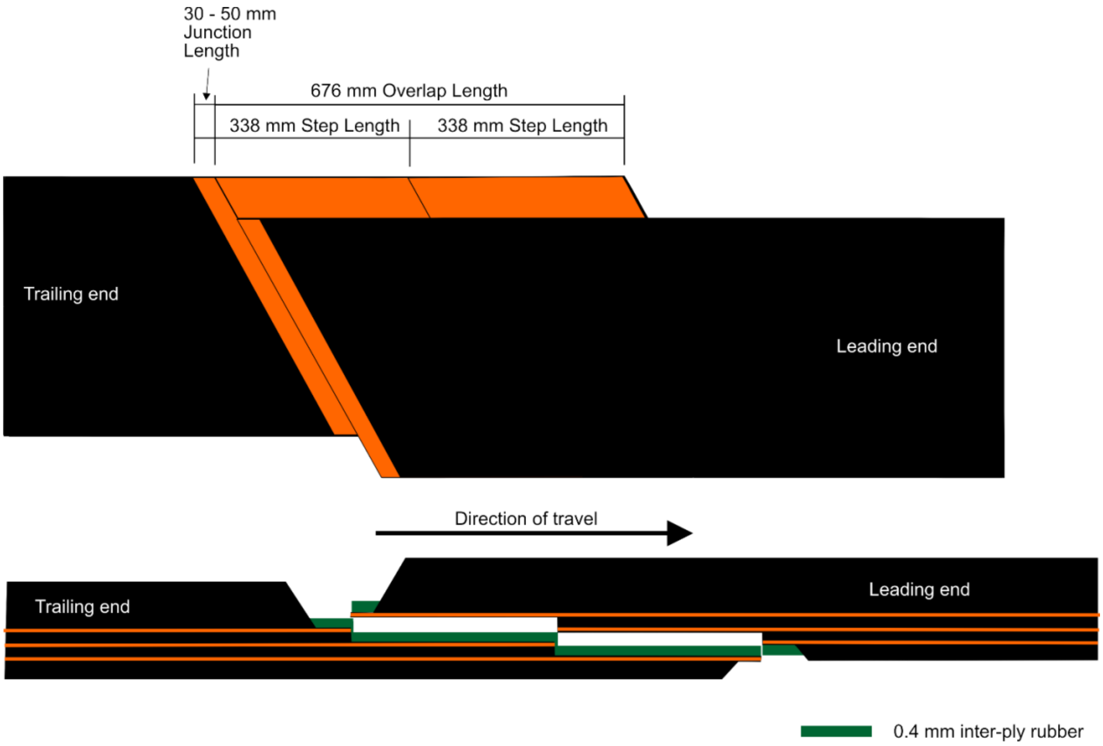


Figure 6.  Splice layout diagram

## SOLID WOVEN CONSTRUCTION

In a solid woven construction conveyor belt, the textile plies are woven together with binders during the weaving process. A typical solid woven construction is shown in Figure 7.

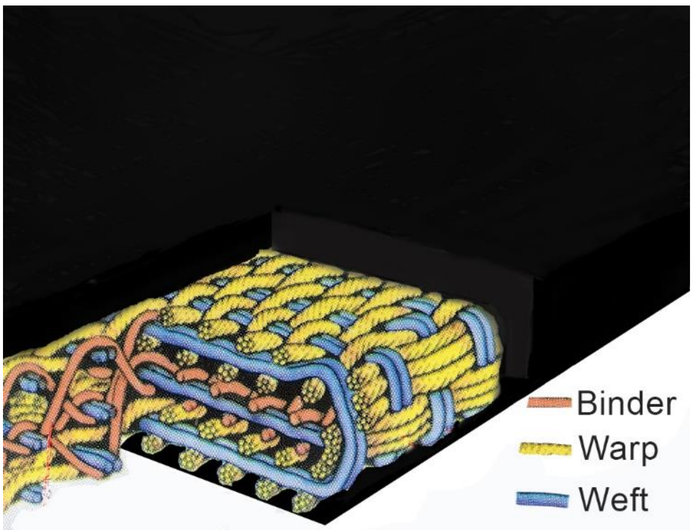


Figure 7.  Solid woven construction

The entire carcass is impregnated with PVC. It is impossible to separate the plies without destroying the belt integrity and therefore a stepped splice option is not possible. A finger splice, as depicted in Figure 8, is used to splice belt ends together.

Each finger is in the shape of an isosceles triangle. The length (height) and base of the triangular fingers are chosen to ensure that the strength of the finger is at least equal to the force required to pull the finger out of the matrix of material in which it is embedded after completing the splice. The strength of the finger is directly proportional to the base dimension. Also, the force required to pull the finger out of the join is directly proportional to the length. Narrow fingers have relatively low strength and consequently the finger length can be made shorter than a wider finger. However, cutting fingers in a solid woven belt is time consuming and the time gained by cutting shorter fingers is not offset by the extra time required to cut many more fingers.

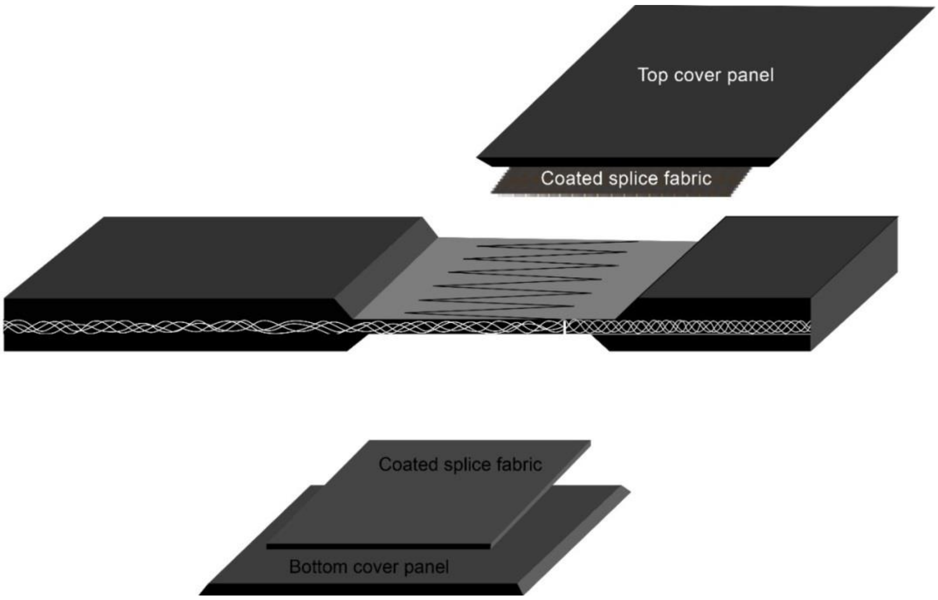


Figure 8. Finger splice

The standard dimension for the base of fingers is 50 mm, so chosen because all standard belt widths are all divisible by 50. The length of the finger is determined by carrying out tests to determine the force to extract the finger. This is dependent on the properties of the material in which the fingers are embedded and the thickness of the material between the fingers. During assembly of the splice, the fingers, which are all cut to the same size, are pulled apart to introduce a gap that will be filled with the splice material. The practical limit to the gap that can be achieved is 2 mm. Referring to Figure 9, the amount by which the fingers should be separated, $x$, to achieve any gap $g$ is

$$x = \frac{\frac{b_w}{2} + g}{\tan\varphi} - L_f$$

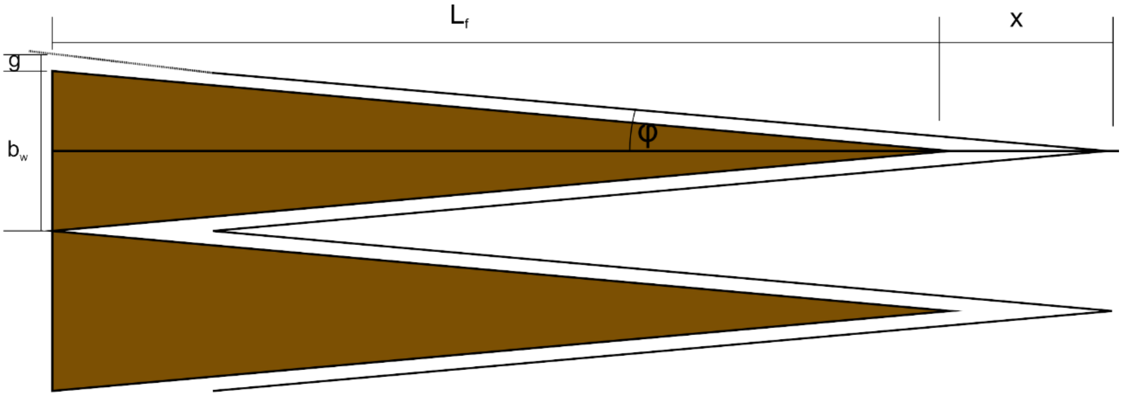


Figure 9.  Finger dimensions

To establish the separation force needed to pull the fingers out of the splice a sample join is made with 100 mm long fingers having a base width of 50 mm. A single finger is cut from the sample join and the force to pull one finger from between the two half fingers is measured in a tensile test machine. The data obtained from a series of tests is used to determine the correct finger length for various width fingers when splicing with the tested splice materials. The strength expected from a finger is derived by the product of the belt class and the finger base width. Hence, if the belt tested is a class $T_b$, the finger length of the sample is $L_{fs}$ and the pull out force obtained is $\tau_g$, then the length of a finger $L_f$ having a base width of $b_w$ is

$$L_f = \frac{T_b \cdot b_w \cdot L_{fs}}{\tau_g}$$

The fingers should be wrapped in an open weave fabric (the splice fabric shown in Figure 8) to help prevent them being separated when subjected to high radial forces at pulleys that have build-up or entrapped material. The strength of this fabric does not play any part in the design of the splice. An open weave fabric design is required to eliminate the possibility of adhesion failure that would detrimentally affect the ability of the fabric to prevent fingers ‘popping’ out. It is also important that the splice fabric extends beyond the finger ends by an amount that would not detract from the role of preventing finger ‘pop-out’.

**STEEL CORD REINFORCED BELTING**

Steel cord reinforced conveyor belting is made up of a carcass of cords embedded in a special rubber formulation with rubber covers on either side of the carcass as shown in Figure 10. The splice is made by laying the cords that have been stripped of rubber next to one another, first from one belt end and then the other. During the laying up of the splice, unvulcanised rubber is placed between each cord. The strength of the splice relies on transfer of forces from one cord to the other through the rubber. The design of the splice relies on carrying out tests to establish the force to pull cords out of a sample that replicates a small section of the splice. The test is referred to as an ‘H-block’ test.

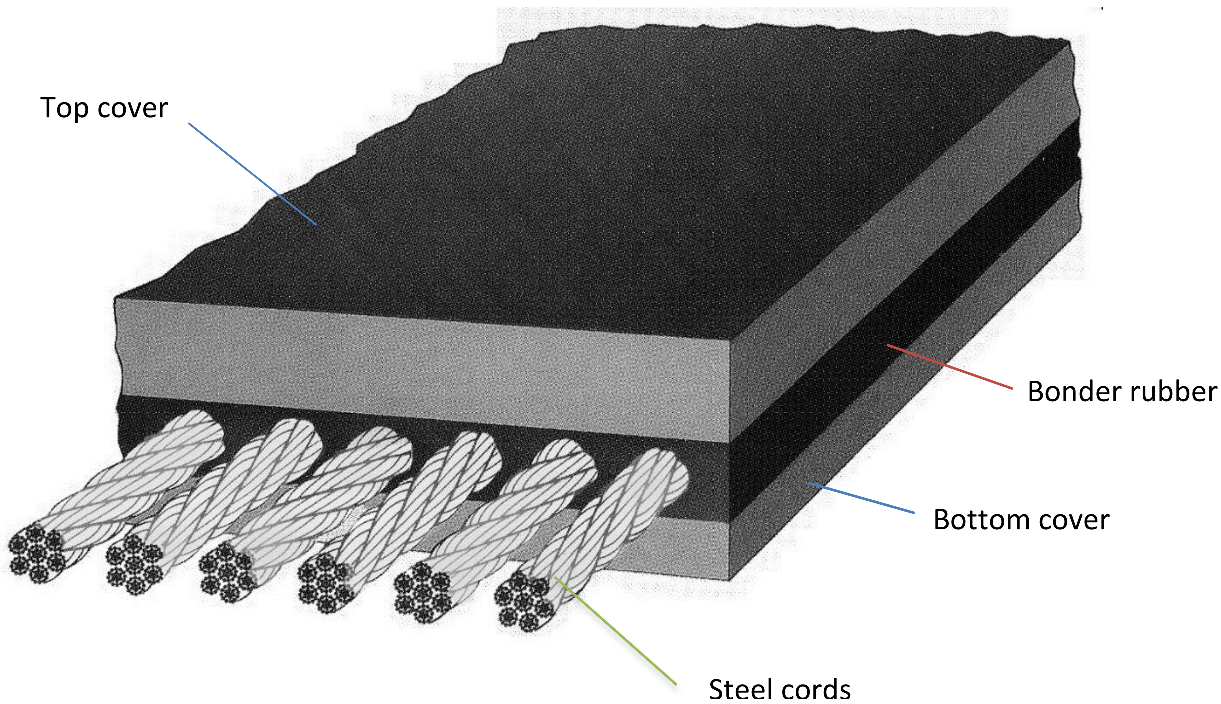

Figure 10. Steel cord reinforced belting

The mould and layout is shown in Figures 11A and 11B. Cords used for the test are taken from a vulcanised belt in the order that closely represents a splice. Five cords are used in the standard H-Block test. Two cords from one side and three from the other as shown in the moulded H-Block in Figure 12. The two outer cords of the group of three are used to ensure more accurate results as experimentation has shown that the force to pull the centre cord out of the rubber is influenced by adjacent cords. The centre cord of the group of three is pulled while the two cords from the opposing side are held. The outer cords are free as shown in Figure 13. The force to pull cords out of the matrix of rubber into which they have been vulcanised is linearly dependent on the embedded length and the cord diameter. So it is standard practice to carry out only a few tests to establish a pull-out force for a particular splice rubber. The test is also used to establish compatibility of splice materials to a particular belt. Research carried out has shown that the pull-out force is reduced significantly if the thickness of rubber between adjacent cords is less than 2.0 mm but does not increase very much for rubber thickness between cords greater than one third of the cord diameter. Therefore, all splices should be designed to have rubber of at least 2.0 mm or one third the cord diameter (whichever is greater) placed between cords from each belt end.

The pull-out force values obtained from the H-Block tests are used to establish a pull-out force in relation to the cord diameter. A safety factor should be applied to the pull-out force. Since the H-Block tests used to determine a pull-out value are conducted in a laboratory environment, a safety factor of 1.5:1 is recommended to allow for the fact that the splices will be carried out in less favourable conditions.

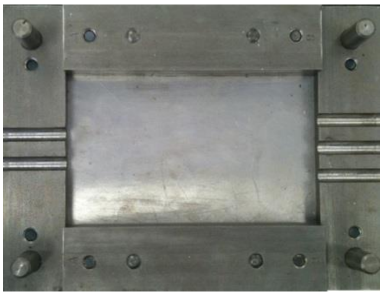

Figure 11A.  Bottom half of mould used in the H-Block test

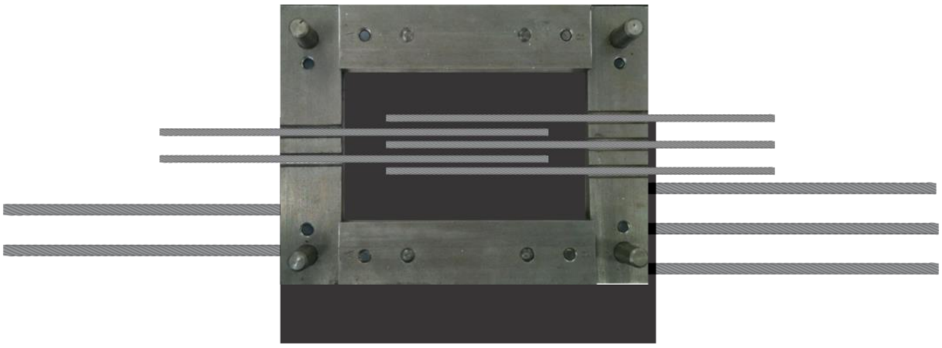

Figure 11B.  Bottom rubber cover and cords positioned in H-Block mould

Figure 12.  Moulded H-Block sample.

Typical value of the cord pull-out force used in design of splices is eight times the cord diameter which implies achieving laboratory H-Block test results for cord pull-out of twelve times cord diameter.

Ideally a steel cord splice has all cords from both belt ends overlapping one another for their full length. This is a Type 1 splice as shown in Figure 13.

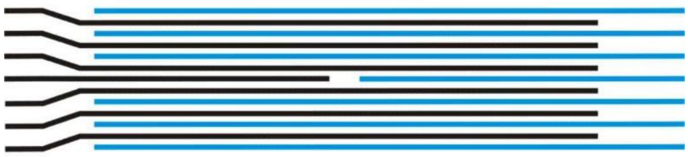

Figure 13. Type 1 splice layout

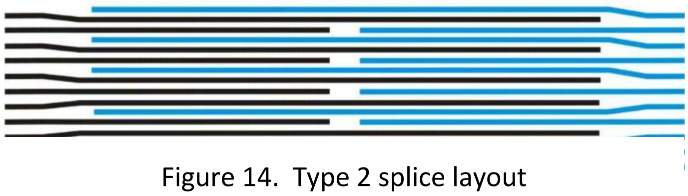

Figure 14. Type 2 splice layout

If the number and diameter of cords is such that it is not possible to have all cords overlapping for their full length then every other cord is cropped and these butt with one another at the halfway point of the splice length as shown in Figure 14.

The decision as to which type of splice should be carried out is based on whether or not the desired minimum gap between cords can be achieved with the lowest numbered splice type. The gap between cords in any specific splice type is

$$S_g = \frac{S_p}{S_p + 1} p_b - d_c$$

Where

$d_c$ = cord diameter
$p_b$ = spacing of cords in the belt to be spliced (cord pitch)
$S_g$ = gap between cords in the splice
$S_p$ = splice type

The distance over which cords should overlap is based on the pull-out force. The pull-out force is the force per unit of embedded length and the embedded length should be such that the force to pull the cord out of the splice is at least equal to the cord breaking strength. The cord breaking strength should be obtained (or provided) by the belt manufacturer. Alternatively, the minimum cord breaking strength can be calculated by dividing the breaking strength of the belt by the number of cords. The breaking strength of the belt is the belt class multiplied by the belt width. Therefore the overlap length is

$$L_0 = \frac{T_b \cdot W}{n_c \cdot \sigma_c}$$

Where

$L_0$ = overlap length
$n_c$ = number of cords in the belt
$T_b$ = belt class
$W$ = belt width
$\sigma_c$ = cord pull-out force per unit length

In addition, the overlap distance must be satisfied by all cords (except the centre cord) in the splice. The length of the shortest overlap in relation to the overall overlap distance is given by the inverse of the splice type. This is the shortest overlap in a Type 1 splice and is equal to the overlap distance while in a Type 2 splice the shortest overlap distance is half the overall overlap distance and so on.

Since the spacing of the cords in the splice is different to the spacing in the belt, the cords must be bent from the original position. The distance over which the bend takes place must ensure that cords are not overstressed. The bend zone should have a length of at least twelve times the cord diameter. For convenience the length of the cord bend zone is rounded up to the nearest 25 mm.

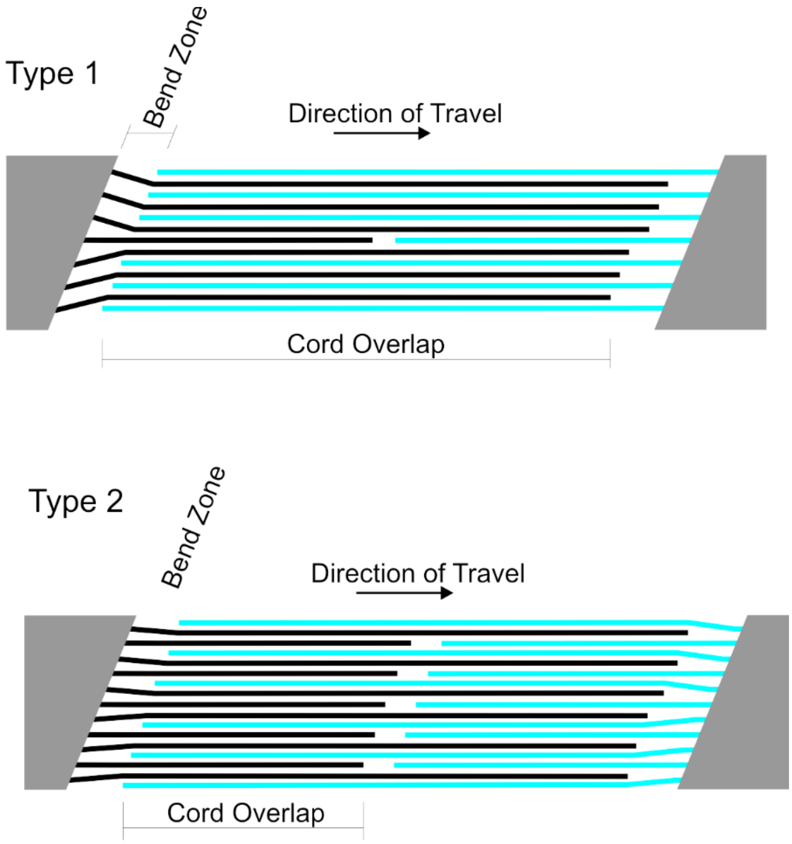

Figure 15. Splice layout diagrams

## CONCLUSION

To ensure maximum splice integrity, the splice dimensions are based on experimental data obtained using the actual materials used in the splice. All splice designs are underpinned by the data obtained from the test programme. Sufficient test work, using varying parameters, are carried out to ensure a high level of confidence in the data used for splice design.

## ABOUT THE AUTHOR

### DAVE PITCHER

Dave Pitcher was the technology manager at Fenner Conveyor Belting.

He has been involved in belt conveyor systems since 1974. His experience covers many different aspects of belt conveyors from design to application of all components.

He has served on standards committees for standardisation of conveyor belting since 1976.

Dave wrote the first computer program for complete design and component selection of belt conveyor systems. He has previously presented papers at the International Materials Handling Conference and is currently serving on the organising committee.

He is a board member of the Conveyor Manufacturers Association (CMA) and a member of the Conveyor Belting and Handbook work group of the CMA.

Dave Pitcher has a Diploma in Datametrics from UNISA and recently passed the CMA Diploma Course in Belt Conveyor Design and Operation.

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