CONVEYOR BELT FLEXURE RESISTANCE AND AS1334.13

Paul Munzenberger[1], Craig Wheeler[2], Brendan Beh[3]

[1]Aspec Engineering Pty. Ltd.
[2]The University of Newcastle, Australia
[3]TUNRA Bulk Solids

The Australian Standard for measuring conveyor belt indentation rolling resistance is AS1334.13:2017 – Determination of Indentation Rolling Resistance of Conveyor Belting. The Standard is designed for measuring indentation rolling resistance but the method described also captures an approximation of conveyor belt flexure resistance. This paper will examine the process by which indentation rolling resistance and conveyor belt flexure resistance are calculated according to AS1334.13 as well as a more accurate method for their calculation that can be undertaken with the same equipment required for the Standard. The application of the two different test methods to troughed conveyors will also be presented and any differences will be considered.

1 INTRODUCTION

Australian Standard AS1334.13:2017 – Determination of Indentation Rolling Resistance of Conveyor Belting presents, as the name implies, a standardized method for measuring conveyor belt indentation rolling resistance [1]. Indentation rolling resistance is the main resistance associated with long conveyor systems [2] and accurate knowledge of it is important when designing these types of conveyor; hence, the reason for the Standard. There are a few different types of machine that can measure indentation rolling resistance with the main difference between them being the test idler roll load application method. Most load application methods involve sandwiching the conveyor belt between a test idler roll and the load application device such as a low friction pad [3] or a large roller [4]; however, it was an alternative method, originally used by Spaans [5], which was chosen as the test method type for the Standard. Spaans' method involves flexing the conveyor belt over the test idler roll and using the belt tension to provide the vertical load.

The equipment required for AS1334.13:2017 is based on the test machine that is shown in Figure 1 and the Standard is informed by over 5 years of experience gained during the operation of the machine for research and commercial work. The machine is owned by the University of Newcastle and operated by TUNRA Bulk Solids. The path of the conveyor belt through the machine is shown in Figure 2 where it can be seen that the two *hold down idler rolls* are forcing the conveyor belt down on either side of the test idler roll to generate the belt flex angle. A vector diagram in Figure 3 shows how the belt tension is converted into vertical test idler roll load. From the vector diagram it is clear that changing the belt tension will change the load applied to the test idler roll. In practice, the spacing of the hold down rolls and the distance by which they force the belt down is representative of a sagging conveyor belt with a hold down roll spacing of 5m and a hold down distance of 50mm being common test settings.

Figure 1 The University of Newcastle's indentation rolling resistance test machine inside its temperature controlled room [6].

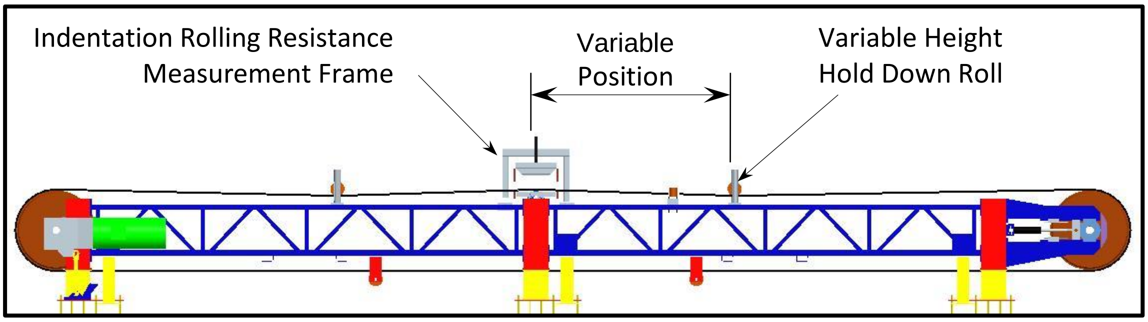


Figure 2 Belt path through the hold-down rolls and test idler roll [6].

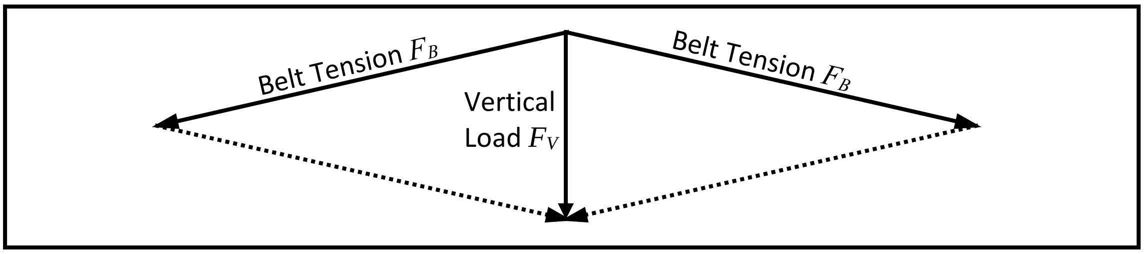


Figure 3 Vector diagram of the conversion of conveyor belt tension into vertical test idler roll load.

Over many years of operation it has been found that the belt flex load application method is suitable for indentation rolling resistance testing, particularly with actual conveyor belt. Conveyor belt must be spliced into a loop to be used on the machine and the splice is always thinner than the remainder of the conveyor belt. The different thickness of the splice is easily handled by the belt flex load application method at any reasonable speed while other load application devices tend to bounce - and destroy load cells – when the splice passes over the test idler roll at anything over 2 – 3m/s. It has also been found that the friction induced on the non-test side of the conveyor belt by alternative load application devices moves the centre of the load application away from the intended location to a position that increases the measured drag force in a way that is difficult to quantify.

Despite its usefulness, the belt flex load application method is not free of flaws. One problem is that it requires large conveyor belt tensions to provide the required vertical test loads, with high loads being much more difficult to achieve at low flex angles. However, the main criticism of the belt flex load application method is that in flexing the conveyor belt over the test idler roll, there is an additional resistance that is measured by the transducers and which must be quantified in order to determine the desired indentation rolling resistance results. Unsurprisingly, this additional resistance is known as conveyor belt flexure resistance.

The remainder of this paper will examine two ways in which conveyor belt flexure resistance results and indentation rolling resistance results can be isolated from combined results gathered using the belt flex load application method and also what the implications of the two methods are when their respective results are used for conveyor design.

2 CONVEYOR BELT FLEXURE RESISTANCE

Conveyor belt flexure resistance is one of the key resistances affecting the efficiency of belt conveyors. Flexure resistance occurs wherever a conveyor belt is bent around belt pulleys and conveyor idler rolls, and also occurs where the conveyor belt sags between sets of conveyor idler rolls. The flexing of a conveyor belt is shown in Figure 4 where the belt flexing between conveyor idler rolls is clearly evident. Despite the less obvious nature of the conveyor belt flexure over the conveyor idler rolls, at least in the provided picture, it is this area that is the main interest.

Figure 4 Conveyor belt flexure on a loaded conveyor with low belt tension.

Due to the geometry of the conveyor, the angle through which the conveyor belt is flexed between conveyor idler rolls is similar to the angle that the conveyor belt is flexed over the conveyor idler rolls. What is different is that the length of the flexed section between the conveyor idler roll sets is only slightly shorter than the pitch of the idler roll sets and the flexed section that is deformed over the conveyor idler rolls occupies the small gap in between. The small gap of the latter section measures on the order of a few centimetres, and since the belt speed is assumed to be the same through each flexure section, the short time of the deformation of the conveyor belt over the conveyor idler roll does not allow enough time for the conveyor belt covers to relax before the flexure is reversed and energy is lost as a result. For the flexure between sets of conveyor idler rolls, the radius of curvature is relatively large – being measured in metres rather than similar in size to the radius of the conveyor idler rolls – and, therefore, strains are small and the relaxation time is relatively long. Low strains and long relaxation times create conditions that absorb less energy and so the flexure resistance between sets of conveyor idler rolls is not as important to the conveyor designer as the flexure resistance of the conveyor belt flexing over conveyor idler rolls.

Direct measurement of the flexure resistance of a conveyor belt bending over a conveyor idler roll is impossible since creating the conditions in an experiment with a conveyor belt and conveyor idler rolls introduces indentation rolling resistance which can be four to five times the size of the flexure resistance force. The University of Newcastle's indentation rolling resistance test machine mimics the belt flexure conditions as part of its operation. With care, the same test machine can be used to indirectly estimate the conveyor belt flexure resistance.

3 DETERMINING CONVEYOR BELT FLEXURE RESISTANCE

Australian Standard AS1334.13:2017 Conveyor Belt Flexure Correction Method

Australian Standard AS1334.13:2017 is a test method for determining conveyor belt indentation rolling resistance. It is written from the point of view of determining indentation rolling resistance and makes no use of the belt flexure results once they are subtracted from the indentation rolling resistance results. The method of determining conveyor belt flexure resistance presented in the Standard was chosen because it requires the least amount of testing and result analysis – thus reducing costs – and it provides conservative indentation rolling resistance results.

In AS1334.13:2017, the conveyor belt flexure resistance is considered to be constant throughout the vertical load range. The constant conveyor belt flexure resistance value is arrived at by grouping measurements taken under the same conditions, but at different loads, and fitting Equation 1 to the group of data. Using the nomenclature shown in the Standard, F_H is the experimentally measured belt resistance – including indentation rolling resistance and conveyor belt flexure resistance, F_V is the load applied to the test idler roll, B is a multiplier, c equals $4/3$ and A approximates the belt flexure resistance as a constant value. An example of the Equation 1 curve fit is given in Figure 5.

$$F_H = A + BF_v^c \tag{1}$$

If the least-squares method is used as the curve fitting procedure for Equation 1, then:

$$A = \frac{\sum_{i=1}^{m}(x_i^c)^2 \sum_{i=1}^{m} y_i - \sum_{i=1}^{m} x_i^c y_i \sum_{i=1}^{m} x_i^c}{m\left(\sum_{i=1}^{m}\left(x_i^c\right)^2\right) - \left(\sum_{i=1}^{m} x_i^c\right)^2} \tag{2}$$

and

$$B = \frac{m\sum_{i=1}^{m} x_i^c y_i - \sum_{i=1}^{m} x_i^c \sum_{i=1}^{m} y_i}{m\left(\sum_{i=1}^{m}\left(x_i^c\right)^2\right) - \left(\sum_{i=1}^{m} x_i^c\right)^2} \tag{3}$$

It is worth noting that Equations 2 and 3 are similar to the standard least-squares curve fit equations that are used to fit straight lines to linear data sets. The equations can be used for the curved fit shown in Figure 5 because of the inclusion of the c term which is not used when fitting straight lines to data points.

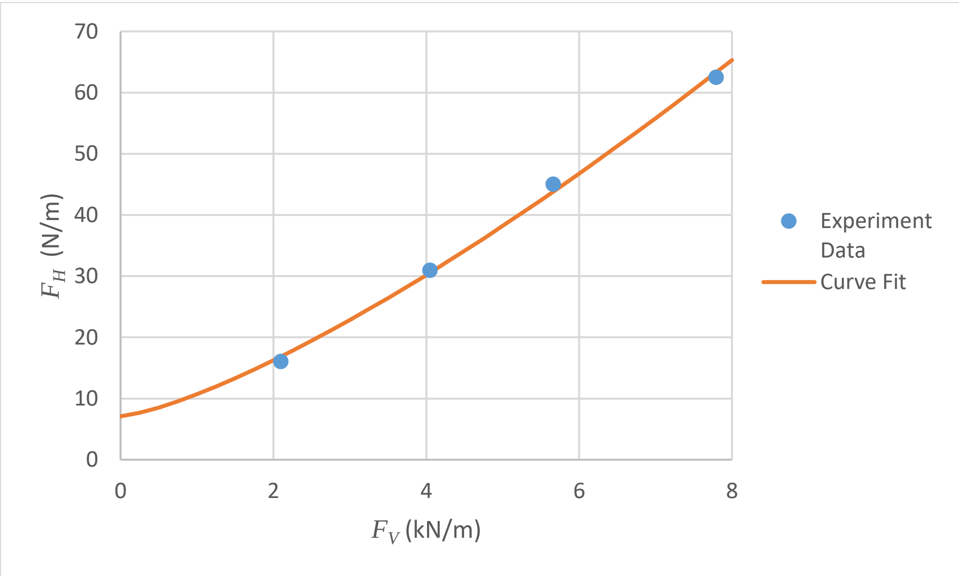


Figure 5 An example of experimental data and the AS1334.13:2017 curve fit.

To complete the AS1334.13:2017 analysis, the conveyor belt flexure resistance value A is subtracted from Equation 1 to produce the indentation rolling resistance curve as shown in Figure 6. Figure 6 also includes the equivalent conveyor belt flexure resistance value for the range of loads included in the graph.

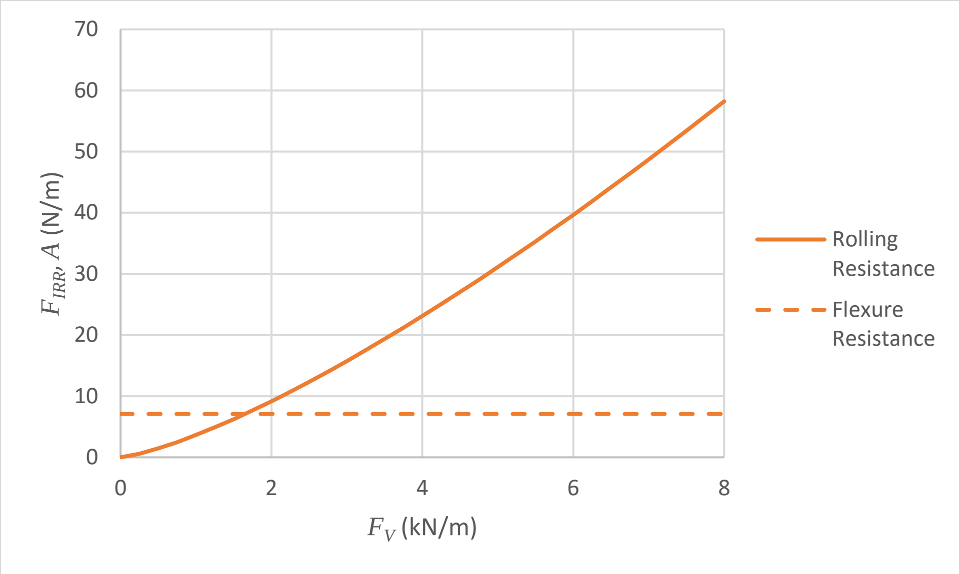


Figure 6 Final AS1334.13:2017 indentation rolling resistance and conveyor belt flexure resistance results.

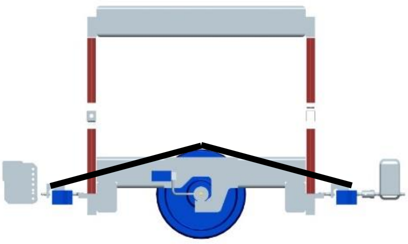
Extended Conveyor Belt Flexure Resistance Correction Method

The extended conveyor belt flexure resistance correction method is a more accurate method of separating conveyor belt indentation rolling resistance and conveyor belt flexure resistance results, with the indentation rolling resistance results being the goal and the similarly improved belt flexure resistance results being a convenient by-product of the procedure.

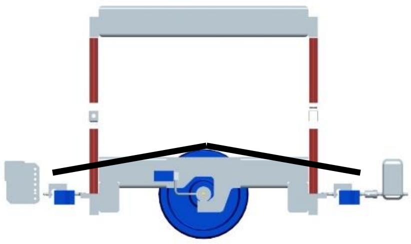
The extended method was developed because there was a need to produce more accurate indentation rolling resistance results that could be directly compared to the theoretical indentation rolling resistance models that were being developed. The method involves testing the conveyor belt repeatedly, each time changing the flexure angle and, as such, requires four to five times as much testing as the AS1334.13 method and an even more onerous analysis procedure.

The extended conveyor belt flexure resistance correction method is designed to work around the impossible need to conduct conveyor belt flexure resistance free indentation rolling resistance tests at 0° belt flexure angle where it is impossible to generate the required vertical test idler roll loads. An examination of Figure 3 and Figure 7 will reveal why testing at 0° cannot generate a vertical load from the belt tension. A possible series of tests required for the extended method, with typical test belt flexure angles provided for each, are shown in Figure 7.

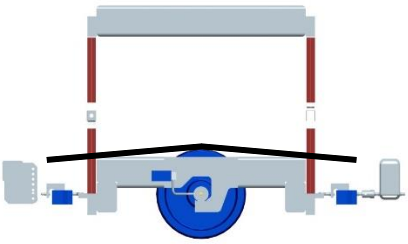
Three tests are shown though it is recommended that at least four different angles be used. From the series of tests, the 0° indentation rolling resistance results can be extrapolated and the extrapolated results are considered to be free of any conveyor belt flexure resistance effects and thus to be more accurate than the results calculated with the AS1334.13:2017 method.



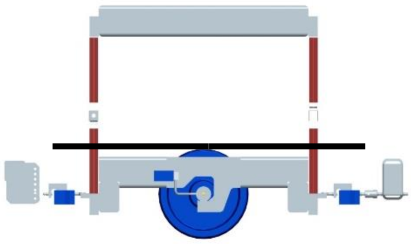
1.5° Flexure angle test.



1.0° Flexure angle test.



0.5° Flexure angle test.



0.0° Flexure angle results not possible to test.
Extrapolated from other tests.

Figure 7 A possible set of tests, with typical flex angles, that could be used extrapolate indentation rolling resistance results. Note that the depictions of the belt flex angle are exaggerated.

The extended conveyor belt flexure resistance correction method results analysis begins in the same manner as the AS1334.13:2017 method where Equation 1 is fitted to the results of each flexure angle test. A set of curve fits from a series of tests is shown in Figure 8. Note that the results are not presented in groups of flexure angle but are grouped according to their belt sag ratios. Up until this point, the term belt flexure angle has been used to help aid the understanding of experimental procedure. The parameter of *belt flexure angle* is not commonly used in conveyor design, while the term belt sag ratio, meaning the ratio of the vertical "droop" of the conveyor belt to the pitch of the conveyor, is used instead and is preferred as it allows the results to be directly applied to the design process without conversion.

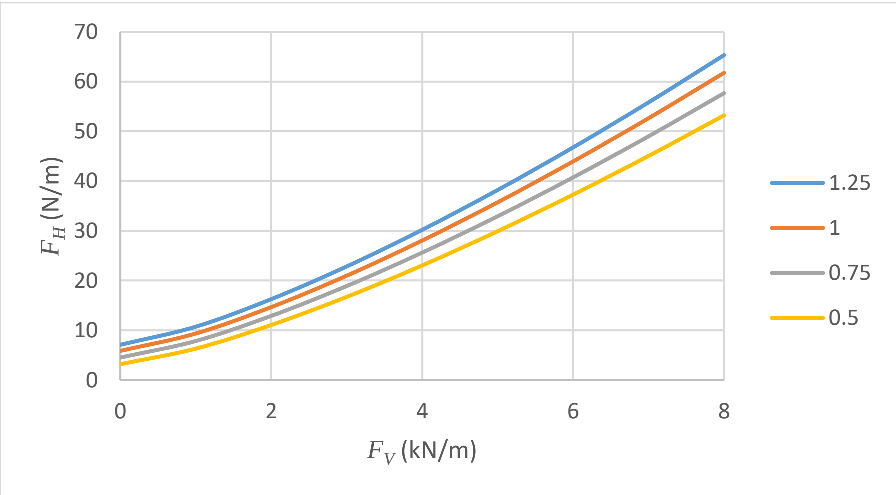


Figure 8 Equation 1 curve fits of resistance results for different belt flexure ratios.

The conveyor belt resistance data points used to create the curves in Figure 8 are not uniformly spaced in the manner that is required for the next step so, using Equation 1 for each curve, belt resistance values are determined for a range of vertical loads that are the same for each curve. The newly calculated data points are grouped according to their vertical loads and graphed as shown in Figure 9. Next, the line equation, Equation 4, is fitted to each data set – the 7kN/m line fit is shown in Figure 9 to illustrate the procedure. In Equation 4, F_H is the total belt resistance which is the sum of conveyor belt flexure resistance and indentation rolling resistance, S is the sag ratio, F_{IRR} is the indentation rolling resistance result that is free of belt flexure resistance and m is the gradient of the line. If desired, F_{IRR} may be calculated with Equation 2 and m may be calculated with Equation 3; though, when calculating values for Equation 4, c equals 1.

$$F_H = mS + F_{IRR} \tag{4}$$

It is possible to conduct the analysis without calculating m, though it is required for visualisation purposes. For the 7kN/m vertical load data set shown in Figure 9 the value of F_{IRR} has been marked and, as can be seen, the F_{IRR} values are simply the y-intercept of the line fits. When all of the values of F_{IRR} are extrapolated from the data for each load, they are curve fitted with Equation 5. The value B in Equation 5 is calculated with Equation 6 where c is again equal to $4/3$.

$$F_{IRR} = BF_v^c \tag{5}$$

$$B = \frac{\sum_{i=1}^{m} x_i{}^c y_i}{\sum_{i=1}^{m} (x_i{}^c)^2} \tag{6}$$

The curve fit of Equation 5, to the set of F_{IRR} data points, is shown in Figure 10. The curve shown in Figure 10 and its equation are used in subsequent conveyor design calculations.

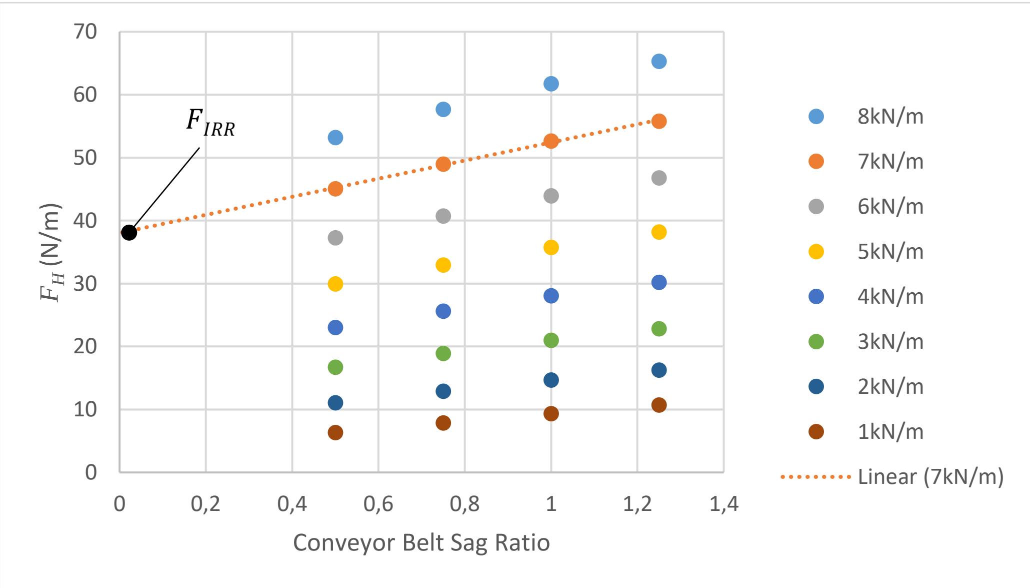


Figure 9 Liner fitting of F_{IRR} data.

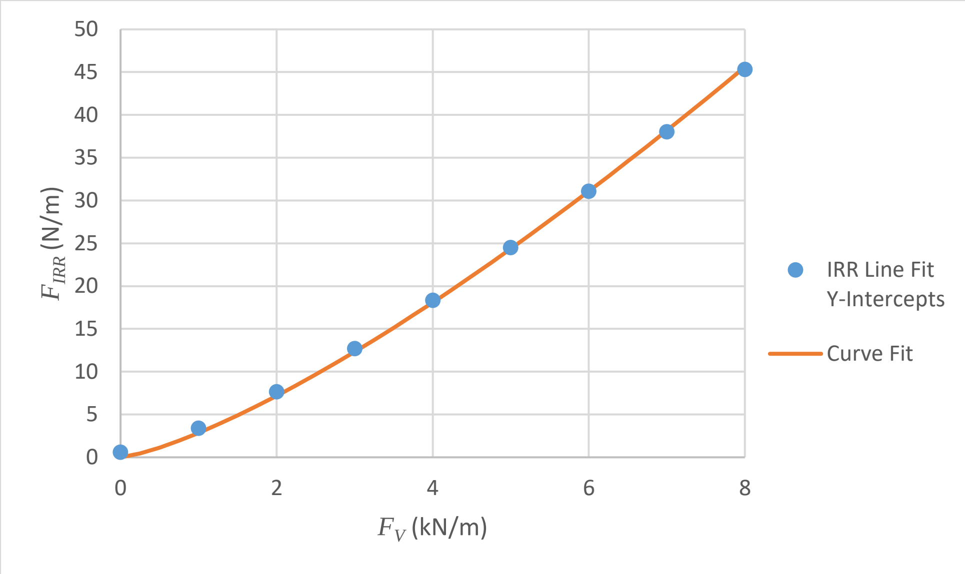


Figure 10 Final indentation rolling resistance result.

Finally, if they are of interest, the conveyor belt flexure resistances can be calculated. The flexure resistance for each sag ratio is simply the difference between the curve shown in Figure 10 and each of the curves shown in Figure 8.

The equations for the flexure resistance curves can be calculated with the least squares curve fit equations or more simply by using Equation 7 where F_{FLX} is the conveyor belt flexure resistance, B_H is the value calculated for B in Equation 1 and B_{IRR} is the value calculated for B in Equation 5. For Equation 7, c is equal to $4/3$.

$$F_{FLX} = (B_H - B_{IRR})F_v^c \tag{7}$$

The conveyor belt flexure resistance results calculated for each belt sag ratio are shown in Figure 11. For reference, the equivalent *constant* conveyor belt sag ratios determined with the AS1334.13:2017 analysis method are also provided for each belt sag ratio.

Interestingly, the belt flexure resistance is not zero under no vertical load. This is because even at zero load the belt is still flexing and will be consuming energy if it is moving. The constant belt flexure resistance results and the extended method results are identical at zero vertical load but diverge significantly at higher loads.

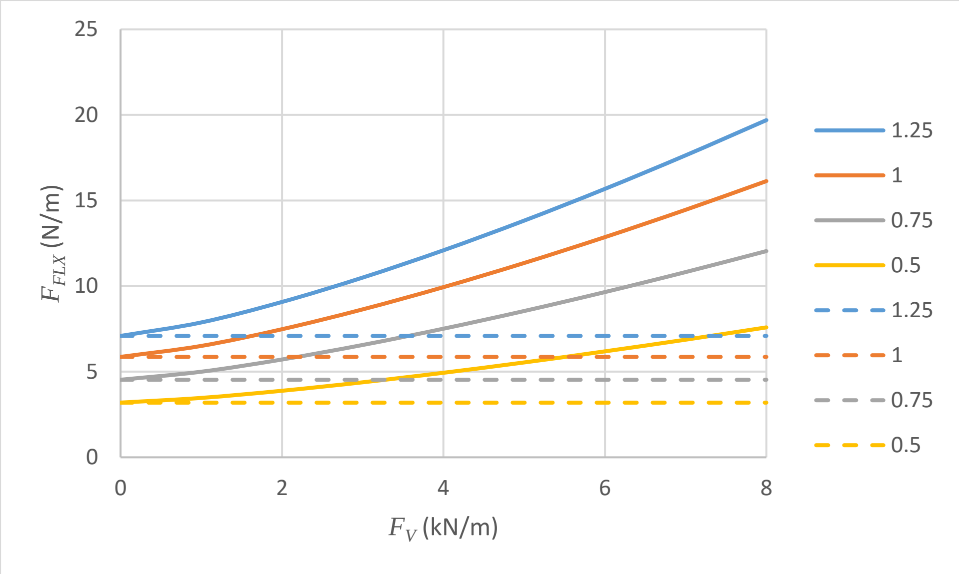


Figure 11 Conveyor belt flexure resistance results using the extended correction method.

4 APPLICATION OF THE INDENTATION ROLLING RESISTANCE AND BELT FLEXURE RESISTANCE RESULTS TO CONVEYOR DESIGN

AS1334.13:2017 offers its user information regarding the conversion of the indentation rolling resistance results determined using the test method. The Standard provides Equations 8, 9 and 10 to calculate the indentation rolling resistance for a three roll troughed idler roll set. In the Equations, with reference to Figure 12, F_{ind} is the indentation rolling resistance force, F_m and F_b are the forces applied to the conveyor idler rolls by the material and the belt respectively, L_c is the length of contact with the centre idler roll and $L_{m,s}$ is the material length along the wing, or side, idler roll. The subscripts c and s relate to the centre and side idler rolls respectively and c equals $4/3$. The value for B is the one that was calculated for the indentation rolling resistance curve fit that is being used.

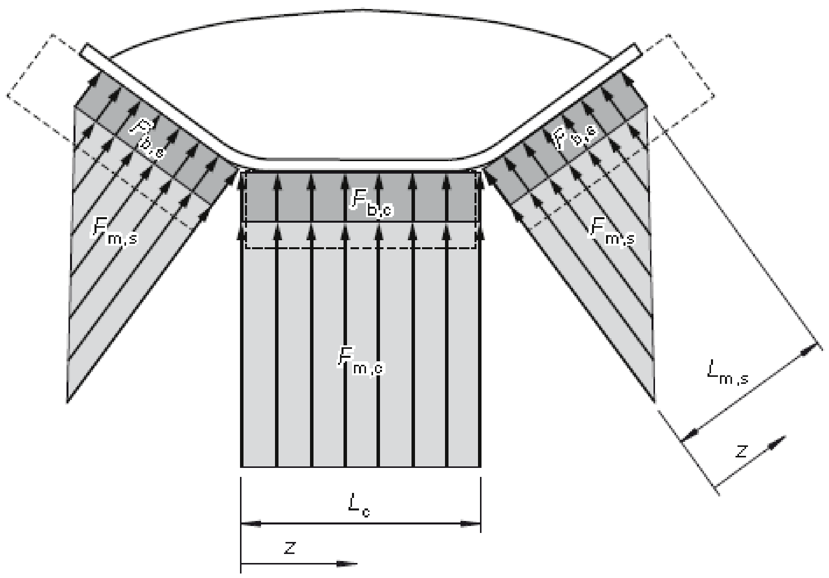
$$F_{ind,c} = B{L_c}^{(1-c)}\left(F_{m,c} + F_{b,c}\right)^c \tag{8}$$

$$F_{ind,s} = \frac{B{L_{m,s}}^{(1-c)}}{2F_{m,s}(c+1)}\left[\left(2F_{m,s} + F_{b,s}\right)^{(c+1)} - {F_{b,s}}^{(c+1)}\right] \tag{9}$$

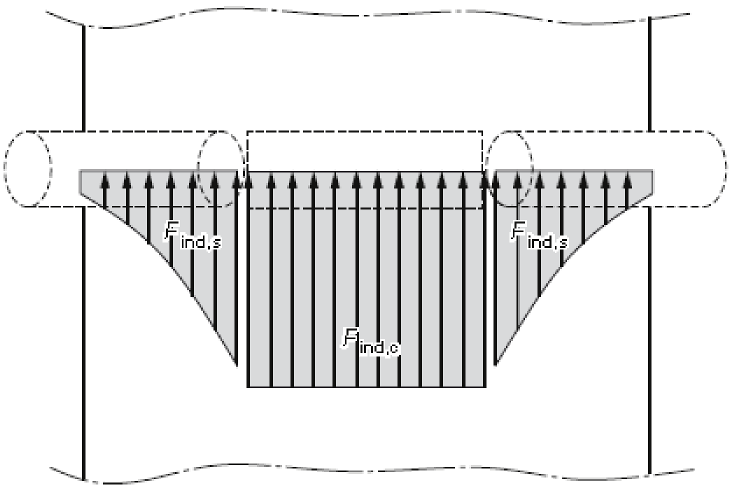
$$F_{ind} = F_{ind,c} + 2F_{ind,s} \tag{10}$$

Equations 8, 9 and 10 are also applicable for use with the conveyor belt flexure resistance curves that are shown in Figure 11. The application of the equations to the conveyor belt flexure resistance results is straight forward with only the value of B changing to suit the different curve. However, Equations 8, 9 and 10 assume that the indentation rolling resistance curve fit passes through the origin, as with the curves shown in Figure 6 or Figure 10, so when they are used with curves that do not pass through the origin such as the conveyor belt flexure resistance curves shown in Figure 11 or the combined indentation rolling resistance and conveyor belt flexure resistance curve shown in Figure 5, an extra step is required. The extra step is simply to determine the y-intercept of the curve and multiply it by the perimeter of conveyor belt that is in contact with the material and add the result to the result determined from Equation 10. The procedure is demonstrated for belt flexure resistance, F_{bfr}, in Equation 11.

$$F_{bfr} = A\left(L_c + 2L_{m,s}\right) + F_{bfr,c} + 2F_{bfr,s} \tag{11}$$



(a) Cross-section showing normal force between idler rolls and belt



(b) Bottom view showing indentation rolling resistance distribution

Figure 12 Approximate normal force distribution and resulting indentation rolling resistance for a three roll troughed conveyor idler roll set [1].

In order to calculate the total resistance for a three roll idler roll set the individual contributions from the indentation rolling resistance, the diverging part of the belt flexure resistance and the constant part of the belt resistance must be individually calculated and summed together. For example, consider a conveyor with the parameters listed in Table 1.

Table 1 Example Conveyor Parameters

Tonnage	2200TPH
Belt Speed	4m/s
Bulk Solids Density	800kg/m^3
Surcharge Angle	20°
Trough Angle	35°
Belt Width	1.2m
Belt Mass	28kg/m^2
Idler Set Pitch	2.5m
Belt Sag Ratio	1%
Centre Idler Roll Length	0.4

The first step is to calculate the conveyor's cross sectional dimensions so that the force on each idler roll can be calculated. No advice for this step is provided in AS1334.13:2017. The calculation steps for the conveyor geometry won't be provided here except to show the cross section of the conveyor that was calculated for the example in Figure 13. From the figure, it should be obvious how the material cross section was discretised and thus how the loads were calculated.

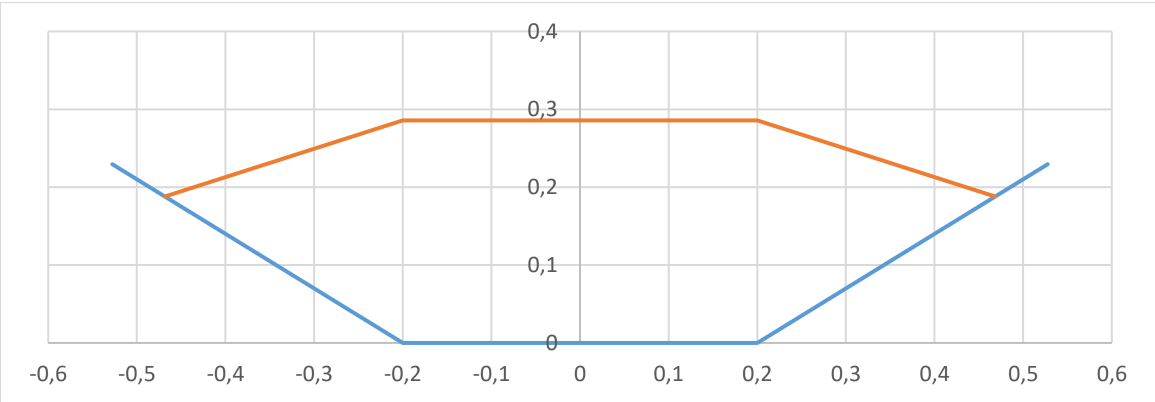


Figure 13 Example's conveyor cross section.

Carrying out the calculations for Equations 8, 9, 10 and 11 for the results calculated with the AS1334.13:2017 method and the data in Table 1 gives the results in Table 2.

Table 2 Example Conveyor Belt Resistance Results for the AS1334.13:2017 Method

$F_{ind,c}$	25.55N
$F_{ind,s}$	2.48N
$\boldsymbol{F_{ind}}$	**30.51N**
$F_{flx,c}$	0.00N
$F_{flx,s}$	0.00N
$F_{flx,const}$	6.19N
$\boldsymbol{F_{bfr}}$	**6.19N**
$\boldsymbol{F_{tot}}$	**36.70N**

Carrying out the calculations in Equations 8, 9, 10 and 11 for the results calculated with the extended method and the data in Table 1 gives the results in Table 3.

Table 3 Example Conveyor Belt Resistance Results for the Extended Method

$F_{ind,c}$	20.86N
$F_{ind,s}$	2.02N
$\boldsymbol{F_{ind}}$	**24.90N**
$F_{flx,c}$	4.70N
$F_{flx,s}$	0.46N
$F_{flx,const}$	6.19N
$\boldsymbol{F_{bfr}}$	**11.80N**
$\boldsymbol{F_{tot}}$	**36.70N**

As expected, the indentation rolling resistance results calculated with the AS1334.13 method results are conservative when compared to the extended method indentation rolling resistance results which are assumed to be more accurate. Perhaps unexpectedly, the total conveyor belt resistance calculated with the resistance results for each method are the same; though, this should not be surprising since the two methods are simply adding the same set of results together in different ways.

In calculating the forgoing, it should be realized, and accounted for, that the material load on the wing idler rolls will have a component that acts normal to the wing idler rolls and will also have a component that is acting parallel to the wing idler rolls. The second component is partly balanced by the same load generated by the material and belt on the opposite side of the conveyor and the remainder of the load is supported by the centre idler roll. In the example presented here, the additional load is assumed to be evenly distributed along the length of the centre idler roll. It should also be noted that the belt sag ratio is assumed to be constant across the width of the conveyor belt which has not been proven to be valid for this paper.

5 CONCLUSION

Two methods of isolating conveyor belt flexure resistance and indentation rolling resistance results from conveyor belt resistance measurements have been shown.

The differences between the two methods has been demonstrated by way of an example conveyor design calculation and it was found that the total conveyor resistance calculated from either set of results was the same.

In developing AS1334.13:2017, the Authors were faced with the decision to choose between the two test methods presented here. It would appear from the example presented that the decision to standardise the simpler, cheaper, test method has not caused any additional errors in the conveyor design calculations.

As expected, the AS1334.13:2017 method can be used to generate conservative indentation rolling resistance results for use in conveyor design projects and conveyor belt flexure resistance results from elsewhere may be incorporated.

Alternatively, the Standard test method allows the indentation rolling resistance and conveyor belt flexure resistance results to be combined provided that the required sag ratios are known before the commencement of the belt testing and test are conducted with the appropriate parameters.

The extended conveyor belt flexure correction method will always be required if there is a need to produce more accurate results that can be compared with theoretical models that only consider one of the resistances in isolation of the other but it does not appear to generate better total conveyor belt resistance predictions when compared with the simpler process.

REFERENCES

[1] Conveyor and Elevator Belting Commitee RU-002, *AS 1334-13: Determination of Indentation Rolling Resistance of Conveyor Belting,* Sydney: Standards Australia, 2017.

[2] M. Hager and A. Hintz, *The Energy-Saving Design of Belts for Long Conveyor Systems,* vol. 13, Bulk Solids Handling, 1993, pp. 749-758.

[3] C. Wheeler, *Analysis of the Main Resistances of Belt Conveyors,* Newcastle: The University of Newcastle, 2003.

[4] NA 008-05-03 AA Working Commitee, *DIN 22123: Indentation Rolling Resistances of Conveyor Belts Related to Belt Width - Requirements, Testing,* 2012.

[5] C. Spaans, *The Indentation Resistance of Belt Conveyors,* Delft: Laboratory for Transport Engineering, 1978.

[6] P. J. Munzenberger, *Three Dimensional Modelling of Conveyor Belt Indentation Rolling Resistance,* Newcastle: University of Newcastle, 2017.

[7] C. Wheeler and P. Munzenberger, *Indentation Rolling Resistance Measurement,* Johannesburg: International Materials Handling Conference, 2011.

[8] F. d. Lynch, *A Finite Element Method of Viscoelastic Stress Analysis with Application to Rolling Contact Problems,* vol. 1, Cambridge: International Journal for Numerical Methods in Engineering, 1969, pp. 379-394.

[9] P. J. Munzenberger and C. A. Wheeler, *The Influence of Steel Cord Conveyor Belt Dimensions on Indentation Rolling Resistance Performance,* Johannesburg: International Materials Handling Conference, 2017.

ABOUT THE AUTHORS

PAUL MUNZENBERGER

Dr Paul Munzenberger is a Mechanical Engineer at Aspec Engineering. Paul competed his Bachelor of Mechanical Engineering in 2007 and gained post graduate qualifications in 2017 – both from the University of Newcastle. Paul is involved with chute and conveyor design and all mechanical aspects of stackers, reclaimers and shiploaders. Paul is also involved in theoretical and experimental research relating to the characterisation of conveyor belt rubbers and testing of conveyor belt.

Paul Munzenberger
Aspec Engineering
Unit 3/166, Wickham, NSW 2293, Australia
Telephone: (+61 2) 4962 2314
Email: paul.munzenberger@newcastle.edu.au

CRAIG WHEELER

Dr Craig Wheeler is a Professor in the School of Engineering at the University of Newcastle, Australia and Associate Director of TUNRA Bulk Solids. He worked as a mechanical engineer for BHP Billiton for eleven years and then as a research fellow at the Centre for Bulk Solids and Particulate Technologies for four years. He was appointed as an academic in the Discipline of Mechanical Engineering in 2000.

Prof Craig Wheeler
Centre for Bulk Solids and Particulate Technologies
School of Engineering, The University of Newcastle
University Drive, Callaghan NSW 2308 Australia
Telephone: (+61 2) 4033 9037
Email: Craig.Wheeler@newcastle.edu.au

BRENDAN BEH

Mr Brendan Beh completed his Bachelor of engineering (Mechanical) in 2008. After graduating from University of Newcastle, he worked as a research assistant with Prof Craig Wheeler to characterise the viscoelastic properties of conveyor belt rubbers, testing of indentation rolling resistance on conveyor belts and other materials handling problems. In 2015 Brendan began a Master’s Degree focusing on conveyor belt flexure resistance. In 2017 Brendan commenced work as a Consulting Engineer for TUNRA Bulk Solids.

Mr Brendan Beh
TUNRA Bulk Solids
The University of Newcastle
University Drive, Callaghan NSW 2308 Australia
Telephone: (+61 2) 4033 9032
Email: Brendan.Beh@newcastle.edu.au