THE SELECTION AND PERFORMANCE OF CONVEYOR STRINGERS

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INTRODUCTION

The design of the stringers on a conveyor is often left to the draughtsman and the experienced draughtsman will give the sizing of the stringers very little thought, other than to ensure that they will fit. While, on the face of it, there is nothing wrong with that, little thought is given to the actual loading on and the behaviour of the stringer. This paper will look at developing a method for estimating the selection of a stringer with respect to the number of idlers and the deflection of the structure. The selection of the stringer with respect to the potential system capacity will be explored.

STRINGER SELECTION

In order to simplify the estimation of conveyor stringers for both surface conveyors and underground mining operations, the relationship between the allowable deflection of the stringer member, the number of idlers per span and the system estimated capacity is explored. By manipulating standard structural formulae, a simple set of rules for the selection of stringers is postulated.

Based on the deflection formulae as published in the *Steel Designer's Manual 4th* Edition, 1972 the deflection of a simply supported member with 1, 2 3 and 4 equally spaced loads respectively is determined. The basic allowable deflection of the stringer at mid-span is specified variously as $\delta = \frac{L}{250}$, $\delta = \frac{L}{300}$ or $\delta = \frac{L}{360}$ and the middle-f the road value of $\delta = \frac{L}{300}$ is utilised as a norm, in accordance with good structural practice and generally accepted deflection limits in industry. The deflection of the loaded beam may be written as follows:

For a single load at mid-span
$$\delta = \frac{PL^3}{48 \cdot E \cdot I} \qquad (1)$$

For two equally spaced loads
$$\delta = \frac{P \cdot a}{24 \cdot E \cdot I}\left(3 \cdot L^2 - 4 \cdot a^2\right) \qquad (2)$$

For three equally spaced loads
$$\delta = \frac{53 \cdot P \cdot L^3}{1296 \cdot E \cdot I} \qquad (3)$$

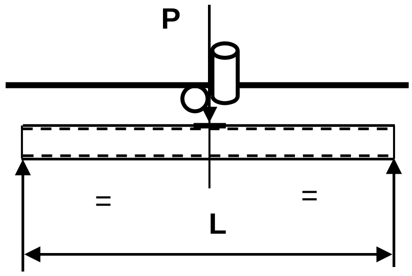
For four equally spaced loads
$$\delta = \frac{41}{768}\left[\frac{4 \cdot P \cdot L^3}{E \cdot I}\right] \qquad (4)$$

In each case,

P = The load at each point, kN
L = The length of the stringer span, m
E = Young's modulus, 210 GPa
I = Section moment of inertia
δ = Deflection at mid-span, m

SINGLE PITCH AT MID-SPAN

The stringer deflection at mid-span is given by $\delta = \frac{PL^3}{48 \cdot E \cdot I}$ m, as noted earlier.



Single Pitch at Mid-Span

The basic deflection is given as $\delta = \frac{L}{300}$ m and the load $P = \frac{L \cdot (B + Z) \cdot g}{2}$ N, since the load is assumed to be carried equally on each stringer. Here the belt mass is written as B kg/m, while Z kg/m is defined as the linear loading of the conveyor burden. The value of $Z = \frac{C}{3{,}6 \cdot S}$ kg/m, where C is the system capacity (t/h) and S is the belt speed, (m/s).

Then $\frac{L}{300} = \frac{P \cdot L^3}{48 \cdot E \cdot I} = \frac{L \cdot (B + Z) \cdot g \cdot L^3}{2 \times 48 \cdot E \cdot I}$ from which $L^3 = \frac{96 \cdot E \cdot I}{300 \cdot (B + Z) \cdot g}$ and

If the actual value of the deflection is written as 1:313, which is a little more stringent than the normal allowable deflection, then the length of the stringer may be given as

$L = \sqrt[3]{\frac{E \cdot I}{3(B + Z) \cdot g}}$, very nearly. (5)

Example:

A system has a capacity of 450 t/h, a belt speed of 2,6 m/s and belting having a mass B = 15,5 kg/m.

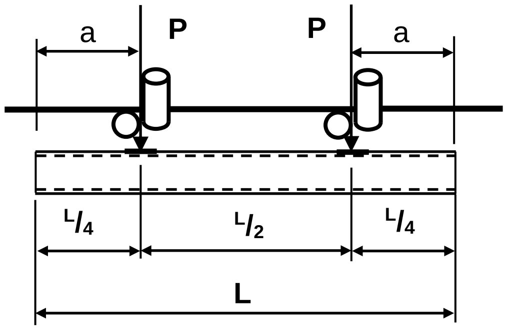
$Z = \frac{C}{3{,}6 \cdot S} = \frac{450}{3{,}6 \times 2{,}6} = 48{,}08$ kg/m. Based on tubular stringers ϕ76×3,5 mm wall to SANS 657/1, the value of $I = 0{,}5429 \times 10^{-6}$ m^4.

From this, the maximum stringer length would be determined as $L = \sqrt[3]{\frac{E \cdot I}{3(B + Z) \cdot g}} = \sqrt[3]{\frac{210 \times 10^9 \times 0{,}5429 \times 10^{-6}}{3 \times (48{,}08 + 15{,}5) \times 9{,}81}} = 3{,}93$ m.

Since the system has a single idler at mid-span, the maximum stringer length would be determined by practical considerations.

TWO EQUALLY SPACED PITCHES

The basic deflection at mid-span is given by $\delta = \frac{P \cdot a}{24 \cdot E \cdot I}\left(3 \cdot L^2 - 4 \cdot a^2\right)$ m, as noted earlier.



Two Equally Spaced Pitches

In this case, $a = \frac{L}{4}$ m and $P = \frac{L \cdot (B + Z) \cdot g}{4}$ N

Then $\delta = \frac{L}{300} = \frac{L(B + Z) \cdot g}{4} \times \frac{L}{4} \times \frac{1}{24 \cdot E \cdot I}\left(3 \cdot L^2 - \frac{4 \cdot L^2}{16}\right)$

$$\delta = \frac{L^2 \cdot (B + Z) \cdot g}{384 \cdot E \cdot I} \times L^2 \cdot \left(3 - \frac{4}{16}\right)$$ and if $\delta = \frac{L}{\chi}$,

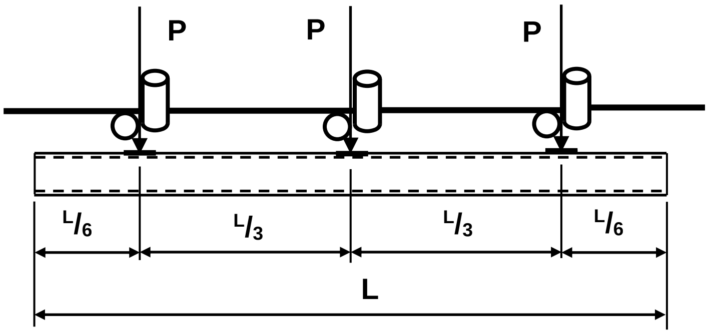
then $\frac{L}{\chi} = \frac{L^4 \cdot (B + Z) \cdot g \times 2{,}75}{384 \cdot E \cdot I}$ and $L^3 = \frac{384 \cdot E \cdot I}{2{,}75 \cdot \chi \cdot (B + Z) \cdot g}$

If $\chi = 419$, then $L = \sqrt[3]{\frac{E \cdot I}{3(B + Z) \cdot g}}$, which is the same expression (equation 5) as for the single load at the centre of the span.

Thus, for the same example as above, the maximum stringer length would be 3,93 m and we could possibly get away with 4,0 m. That implies a maximum idler pitch of 2,0 m and again, practical considerations would apply.

THREE EQUALLY SPACED PITCHES

The basic deflection at mid-span is given by $\delta = \dfrac{53 \cdot P \cdot L^3}{1296 \cdot E \cdot I}$ m, as noted earlier.



Three Equally Spaced Pitches

In this case, $P = \dfrac{L \cdot (B + Z) \cdot g}{6}$ N as before and $\delta = \dfrac{53 \cdot P \cdot L^3}{1296 \cdot E \cdot I}$ m from the handbook.

if $\delta = \dfrac{L}{\chi}$, then $\dfrac{L}{\chi} = \dfrac{53 \cdot P \cdot L^3}{1296 \cdot E \cdot I}$ and $\dfrac{1296 \cdot L}{53 \cdot \chi} = \dfrac{L \cdot (B + Z) \cdot g \cdot L^3}{6 \cdot E \cdot I}$

then $L^3 = \dfrac{1296 \times 6 \cdot E \cdot I}{53 \cdot \chi \cdot (B + Z) \cdot g}$ and if $\chi = 440$, then $L = \sqrt[3]{\dfrac{E \cdot I}{3(B + Z) \cdot g}}$, as equation 5

which is now becoming familiar.

For the same example as above, the maximum stringer length would again be 3,93 m and we could possibly get away with 4,0 m. That implies a maximum idler pitch of 1,33 m and we would probably have to reconsider the stringer section, if the idler pitch is required to be greater than this, since an idler pitch greater than 1,33 m could imply a longer stringer.

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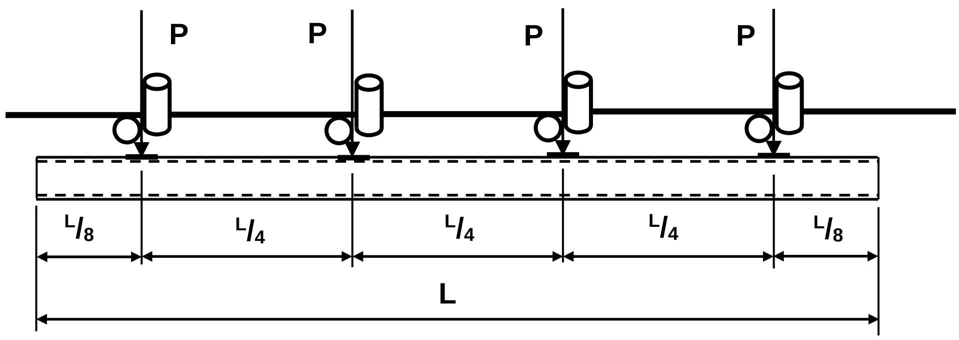
FOUR EQUALLY SPACED PITCHES

The basic deflection at mid-span is given by $\delta = \frac{41}{768}\left[\frac{4 \cdot P \cdot L^3}{E \cdot I}\right]$ m from the handbook



Four Equally Spaced Pitches

In this case, $P = \frac{L \cdot (B + Z) \cdot g}{8}$ and $\delta = \frac{41 \cdot P \cdot L^3}{788 \cdot E \cdot I}$ from the handbook.

If $\delta = \frac{L}{\chi}$, then $\frac{L}{\chi} = \frac{41 \cdot L^4 (B + Z) \cdot g}{6144 \cdot E \cdot I}$ and if $\chi = 450$, then $L = \sqrt[3]{\frac{E \cdot I}{3(B + Z) \cdot g}}$ very nearly.

which is again the familiar equation (5) as determined in the other cases.

Again, for the same example as above, the maximum stringer length would be 3,93 m and we could possibly get away with 4,0 m. That implies a maximum idler pitch of 1,0 m and economic considerations may apply, depending on the required idler pitch. We would probably have to reconsider the stringer section, if the idler pitch is required to be greater than 1,0 m.

From this, it can be seen that, if the length of the stringer is limited, the deflection will become more stringent as the number of idler pitches increases. Alternatively, the idler pitch would decrease for the same stringer section, as the number of idler pitches is increased.

For conveyor stringers, the deflection of the stringers at mid-span is accepted as about 1/300 for a stringer with a single idler mounted at centre span as noted before. This, of course, implies that the stringer length would not be greater than an idler pitch and is therefore not likely to be much longer than about 1,6 m for underground structures, with a maximum probably about 2,0 m, as we noticed in our example earlier. Indeed, at pitches greater than about 2,0 m. it would probably be more appropriate to mount the individual idlers on separate line-stands, since the steelwork required between each idler would really serve no purpose, other than a rather expensive sheeting support. In this case, of course, with line stands the stringers fall away and the argument is closed then and there.

On the basis of a deflection limit of 1/300, the maximum allowable deflection for a stringer with a single idler mounted at centre span and 2,0 m long would be determined as $\delta = \frac{2}{300} = 6{,}6 \times 10^{-3}$ m when the total load of material, idlers and belting is considered.

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As the number of idlers is increased per stringer span, the total load on the stringer will increase, for the same belt capacity and speed. For this reason, the deflection limits must become more stringent and the length of the stringer will become limiting. Thus, for a common approach, the maximum length of a stringer, with up to 4 equally spaced idlers, may be expressed as $L = \sqrt[3]{\frac{E \cdot I}{3(B + Z) \cdot g}}$, as determined above in equation 5, where

E = Young's modulus = 210 × 10^9 Pa
I = Moment of Inertia of section m^4
Z = Material and belt linear load kg/m
B = Belt mass kg/m

For the general case, the mass of the belting is not always known. However, as an average, the mass of the belting can be estimated at about 16,7% of the linear mass of material (which is a very useful coincidence!). However, the proportion of the mass of the belting could be much greater than 17% and where this is known, equation 5 above will be used.
When the belting mass is unknown, then $B = (0{,}167 \cdot Z)$ kg/m and $Z' = (Z + B) = 1{,}167 \cdot Z$ kg/m.

If this is substituted into equation 5, this becomes $L = \sqrt[3]{\frac{E \cdot I}{3{,}5 \cdot Z' \cdot g}}$ ———— (6)

Using this equation, it is therefore possible to estimate the maximum safe capacity of a system on the basis of the stringer size, support and arrangement.

Manipulating equation 6, $L^3 = \frac{E \cdot I}{3{,}5 \cdot Z' \cdot g}$ m when the stringer length is not specified and the material and belting linear loading can be simply estimated by

$Z' = \frac{E \cdot I}{3{,}5 \cdot L^3 \cdot g}$ kg/m ———— (7) when the stringer length is specified.

TUBULAR STRINGERS

Stringers for underground operations are commonly specified with tubular section, particularly when link suspended idlers and fixed-form suspended idlers are used. Tubular stringers are also sometimes used on surface overland conveyors, though this is relatively uncommon in South Africa. In addition to the tubular sections, standard rolled steel sections are used, particularly in surface, overland and in-plant operations.

The stringers analysed are based on ϕ76 x 3,5 wall tube and ϕ102 x 3,5 wall tube to SANS 657/1, because these appear to be very common in South African coal mines. The stringer lengths considered were from 3,0 m up to 6,0 m long in 0,5 m increments. Since the developed formula holds for any combination of idler pitch, the idler pitches were not figured in this analysis.

The values of I for the tubes are determined from the standard formula,

$I = \frac{\pi(D^4 - d^4)}{64}$ ———— (8) and results in

I = 0,5429 x 10^{-6} m^4 for the ϕ76×3,5 tube and

I = 1,315 x 10^{-6} m^4 for the ϕ102×3,5 tube.

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From equation 6 above, $Z' = \frac{E \cdot I}{3{,}5 \cdot L^3 \cdot g}$, and the values are substituted as appropriate.

The value of E is accepted as 210 GPa

VALUES OF Z' AND C' FOR SELECTED TUBULAR STRINGERS								
Stringer	□×10^{-6}	3	3,5	4	4,5	5	5,5	6
□76×3,5	0,5429	122,98	77,45	51,88	36,44	26,56	19,96	15,37
□102×3,5	1,315	297,88	187,59	125,67	88,26	64,34	48,34	37,24
System Specific Capacity t/h/m/s		442,7	278,8	186,8	131,2	95,6	71,8	55,3
		1072,4	675,3	452,4	317,7	231,6	174,0	134,1

Table 1: Value of Z' and C' for Tubular Stringers

Since the capacity is related to the linear loading by $Z = \frac{C}{3{,}6 \cdot S}$ kg/m as defined earlier and we have already estimated the mass of the belting as $B = (0{,}167 \cdot Z)$ kg/m, it follows again that the *specific* capacity of a system, at the base speed of 1,0 m/s can be estimated as tons per hour per meter per second of belt speed. Thus $C' = (3{,}6 \cdot Z' \cdot S)$ t/h and S is set at 1,0 m/s.

As is to be expected, the specific capacity of the system is rather limited at 1,0 m/s. However, the relationship between the speed and the capacity is direct. Therefore, any speed can be estimated by dividing the required capacity by the specific capacity as determined. For example, for a 4,0 m stringer length with ϕ102×3,5 tubing stringers, if the required capacity is (say) 1200 t/h with 4 idlers per stringer, then the belt speed must be not less than $S = \frac{1200}{452{,}4} = 2{,}65$ m/s and the stringer deflection would be within the normal limits. . Any capacity beyond that limit will result in a greater deflection of the stringers, with the possibility of failure.

CHANNEL STRINGERS

The formulae hold true for channel stringers as well and the following sections have been considered: 100x50; 140x60, 160x65, 178×54, and 180×70 since these are relatively common.

In the case of channel stringers, the values of I may be summarised as

$I_{100/50}$ = 2,053 x 10^{-6} m^4
$I_{140/60}$ = 6,048 x 10^{-6} m^4
$I_{160/65}$ = 9,247 x 10^{-6} m^4
$I_{178/54}$ = 8,597 x 10^{-6} m^4 and the availability of this (traditional) section must be verified.
$I_{180/70}$ = 13,54 x 10^{-6} m^4

Based on the values of I and the stringer length, the maximum value for the linear loading of the belt and burden may be obtained.

VALUES OF Z' FOR SELECTED CHANNEL SECTION STRINGERS								
Stringer	□$\times 10^{-6}$	STRINGER LENGTH (m)						
		3	3,5	4	4,5	5	5,5	6
100×50	2,053	465,06	292,86	196,20	137,80	100,45	75,47	58,13
140×60	6,048	1370,03	862,76	577,98	405,93	295,93	222,33	171,25
160×65	9,247	2094,69	1319,10	883,70	620,65	452,45	339,93	261,84
178×54	8,597	1947,45	1226,38	821,58	577,02	420,65	316,04	243,43
180×70	13,540	3067,17	1931,51	1293,96	908,79	662,51	497,75	383,40

Table 2: Value of Z' for Channel Stringers

SYSTEM SPECIFIC CAPACITY C' t/h/m/s							
	STRINGER LENGTH (m)						
Stringer	3	3,5	4	4,5	5	5,5	6
100×50	1674,2	1054,3	706,31	496,06	361,63	271,7	209,28
140×60	4932,1	3105,9	2080,7	1461,4	1065,3	800,4	616,51
160×65	7540,9	4748,8	3181,3	2234,3	1628,8	1223,8	942,61
178×54	7010,8	4415	2957,7	2077,3	1514,3	1137,7	876,35
180×70	11042	6953,4	4658,3	3271,6	2385	1791,9	1380,2

Table 3: Value of C' for Channel Stringers

The capacities obtained are independent of the belt width, since they relate to a linear loading only. The capacities may be compared to the theoretical capacity of various widths of conveyor, to assess the reality of the values obtained.

Since the linear loading of a conveyor is derived from $Z = \frac{C}{3{,}6 \cdot S}$ kg/m and we have set S = 1,0 m/s for the specific capacity, it follows that C = 3,6·S·Z t/h per m/s and these values are reflected in the tables above. In addition, the capacity of the conveyor is a function of the cross-sectional area of the material on the belt, for the various belt widths, idler configurations and surcharge angles. The area at 100% loading is based on the freeboard as derived from the standard ISO method. The cross-sectional area for various belt parameters are shown in table 3 below. The range reflects that as commonly found on many mines in South Africa.

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BELT LOADING AND SPECIFIC CAPACITY

Belt width	Idler	Wing roll	Area m²	Specific Capacity
1050	3	35°	0,1248	404,35
1200	3	35°	0,1658	537,19
		45°	0,1787	578,98
1350	3	35°	0,2125	688,50
		45°	0,2290	741,96
1500	3	35°	0,2650	858,60
		45°	0,2856	925,34
1800	3	35°	0, 3874	1255,18
		45°	0,4173	1352,05
	5	35°	0,3651	1182,92
		45°	0,4043	1309,93

Table 4: Belt cross-sectional area

The capacity of the conveyor is then based on the following relationship:

$C_{dc} = 3600 \cdot A_{100} \cdot S \cdot D$ t/h, – (5) where the material bulk density is represented by D t/m³. In the case of coal, the bulk density of ROM coal may be estimated at 0,9 t/m³ and the maximum capacity of the conveyor will be as shown in the appropriate column of table 3. These values can then be compared to the values obtained from the stringer tables.

COMPARISONS

From the comparison, we can see that the linear loading for ϕ76 mm tubing is reasonably limited, with the specific capacity limited accordingly. The maximum specific capacity for the ϕ76 tubing would be practically restricted to stringers with a 3,0 m length and would be limited to 1200 mm wide belting, running in 35° idlers. Any width greater than 1200 mm would have a potential capacity in excess of the stringer capability. Of course, since the stringer capability is a cube function of the span, the carrying capability of the stringers will be drastically reduced for the 4,5 m span, as shown in the tables.

Stringers of ϕ102 tube have a higher capacity potential and the capacity limitation with the 3,0 m span would allow belting up to and including 1800 mm wide belting . The stringer span at 4,5 m with the ϕ102 tube would be restricted to a specific capacity of only 400,45 t/h/m/s, which, again, is limited to a 1050 mm wide belt.

From the analysis, it would appear that tubular stringers should be limited to a span of 3,0 m only, whether the section is ϕ76 mm or ϕ102 mm tube.

A selection of a heavier wall tube could be considered. Consequently, the effect of increasing the wall thickness of the ϕ76 mm tube from 3,5 to 4,0 mm was investigated. In the case of the 3,0 m span, this resulted in an increase in the carrying capacity of 12% and this must be compared to the increase in mass of about 13%. For this reason, this option was not pursued any further, since it is unlikely to result in any economic benefit.

The analysis of channel stringers shows a greatly increased capacity, as a result of the much larger moment of inertia of the sections. Comparing the capacity values from table 2 to the maximum values in table 3, we can see that the 100 x 50 channel stringer, at a span of 3,0 m will be capable of supporting belt loads for the whole range of belt widths, for both 35° and 45° idler forms.

The same section at 4,5 m span will be limited to belting 1350 mm wide running in 35° idlers.

It must be repeated that the capacities shown are *specific* capacities, at 1,0 m/s, as shown in the example above.

COMPARISON WITH INSTALLATION TOLERANCES

The expected loaded deflection of the stringers should not influence the installation tolerances of the conveyor system. Vertical tolerances pertain to the junction of adjacent stringers and a limit of 3 mm is set on the alignment of the joint. The superelevation tolerance is further set at $\frac{W}{600}$ for stringers with fixed form idlers and $\frac{W}{600}$ for stringers with link suspended idlers. Here, W represents the belt width. In addition, the maximum vertical displacement of any adjacent idlers is limited to 1,0 mm. From, this, it can be seen that the deflection limits of the stringer sections as proposed are far more stringent than the installation tolerances.

CONCLUSION

A simplified approach to the selection of conveyor stringers is presented. The selection is based on an increasingly stringent deflection allowance as the number of idlers supported on each stringer increases. By manipulation, estimates of capacities for existing structures can be made.

AUTHOR'S CV

Graham Shortt has recently retired from Anglo American after 25 years service in the materials handling section of Specialized Engineering. However, he still endeavours to remain active in the field of materials handling, especially belt conveyors.

Mr Shortt obtained a Master of Engineering Practice (Bulk Solids Handling) from Tunra in Australia and is also a Fellow of the South African Institute of Materials Handling.

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