STRESSES PRODUCED IN FRONT LEGS AND BACKSTAYS BY THE TENSION IN THE ROPES FOR VARIOUS POSITIONS OF THE BACKSTAYS.

	Tensions in Ropes—Tons.		Stresses Induced—Tons.		Factor of Safety.	Breaking Strengths in tons = Stress × Factor of Safety.		Overturning Moment.	Moment of Stability.	
	Sloping.	Vertical.	Back Stays.	Front Legs.		Back Stays.	Front Legs.			
A.—Backstay Parallel to Resultant, *i.e.*, Bisecting the Angle between the Ropes.										
Case I (a)	10·5	10·5	19·25	—	20	385	—			Fig. IV.
(b)	16·9	16·9	31·0	—	15	465	—			
Case II	112·5	112·5	206·0	—	3·5	720	—			
Case III	112·5	6·5	—	—	—	—	—	112·5 × x	w × y + 6·5 (y + z)	
B.—Backstay Arranged According to Common Rule.										
Case I (a)	10·5	10·5	14·75	5·5	20	295	110			Fig. V.
(b)	16·9	16·9	22·7	8·85	15	341	133			
Case II	112·5	112·5	158·0	59·0	3·5	553	262			
Case III	112·5	6·5	—	—	—	—	—	112·5 × x	w × y + 6·5 (y + z)	
C.—Backstay Parallel to Sloping Rope.										
Case I (a)	10·5	10·5	10·5	10·5	20	210	210			
(b)	16·9	16·9	16·9	16·9	15	254	254			
Case II	112·5	112·5	112·5	112·5	3·5	394	394			
Case III	112·5	6·5	—	—	—	—	—	112·5 × rad. of pulling.	w × y + 6·5 (y + z)	

By an inspection of the table, it is evident that when the back-stay bisects the angle between the ropes, the front leg is unstressed, and could, theoretically, be done without. When arranged according to the common rule mentioned before, a certain amount of the stress falls on the front legs, but the major portion is still borne by the back-stays. In each of these positions there is an overturning effect.

The nearer the position of the back-stay approximates to parallelism with the sloping rope, the less becomes the stress in the back-stays and the greater that in the front legs, and the overturning moment also becomes less until when parallel to the sloping rope the stress in back-stays equals the stress in front legs equals the tension in ropes, and the overturning moment is a minimum.

Probably the most satisfactory arrangement is to place the back-stay as nearly as possible parallel to the sloping rope. The front support must always be present for satisfactory construction, so that it might as well be designed to take a fair share of the stress due to winding. The chief objection to this arrangement is the extra length required. This is to some extent set off by the reduced size required.

The results above tabulated show that Case II., where the vertical and sloping pulls each equals the breaking strength of rope, when a factor of safety of 3.5 has been allowed, requires the greatest breaking strength for front legs and back-stays. They should therefore be designed for this value of the breaking strength. Case III. will in every position of the back-stays produce the maximum overturning effect.

Bracing Between Front and Back Legs.

This is introduced in order to stiffen the structure as a whole from front to back, and also to stiffen the legs by reducing the effective lengths of the columns. Length of column may be taken as equal to the distance between points of attachment of bracing.

Bracing Between Front Legs, and Between Backstays.

This is to stiffen the structure sideways and to resist the stresses induced by wind and pressure.

The slope of the rope from winding pulley to drum varies considerably. In the case under consideration, it is taken as 45 degrees.

These results may be applied to the design of a head frame for winding under the conditions stated. Diagram of proposed frame is shown; back-stays are parallel to rope, which is inclined 45 degrees to the horizontal. Material to be used—Oregon pine (Douglas Spruce).

If the landing stage or brace is required to be at an elevation of 25 feet above ground, total height to centre of pulley will be:—

$$\begin{aligned} &25 \text{ ft.} + \text{height of cage} + \text{circumference of 10 ft. winding drum} \\ &\quad + \text{height above detaching platform} \\ &\quad = 25 \text{ ft.} + 9 \text{ ft. (say)} + 31{\cdot}4 \text{ ft.} + 10 \text{ ft. (say)} \\ &\quad = 75 \text{ ft. (nearly).} \end{aligned}$$

The stresses produced in Case II., allowing for dynamic effect, are 112.5 tons in both front legs and back-stays. The front legs will have to bear the weight of the winding pulley and supports and its own weight, about five tons in all. The stress in the back-stay will also be increased to some extent, but this has been allowed for in the calculations which follow, so also has the slight increase due to the batter of the posts.

Each front leg must therefore be designed to have a breaking strength

$$= \frac{3{\cdot}5\ (112{\cdot}5 + 5{\cdot}0)}{2} = 209 \text{ tons}$$

factor of safety taken is 3.5.

Each back-stay must have a breaking strength

$$= 3{\cdot}5 \times \frac{112{\cdot}5}{2} = 194 \text{ tons}$$

Take values as 210 tons on each front leg and 200 tons on each back-stay.

J. B. Johnson ("Materials of Construction") gives the following formula for calculating columns of white pine with square ends, which may be used to calculate Oregon columns, since the strength of white pine and Oregon are very nearly the same. The columns are practically fixed at the ends, so any error will be on the safe side.

The formula is:—

$$\text{Breaking strength in lbs. per sq. inch} = 3{,}600 - {\cdot}72\ (l/h)^2$$
where l = length of column in inches
h = least lateral dimensions.

Front Legs.

$l = 25$ ft.; assume $l/h = 30$

$$\begin{aligned} \text{Breaking strength} &= 210 \times 2{,}240 \\ &= (3{,}600 - {\cdot}72 \times 30^2) \text{ area of cross section} \\ &= 2{,}970 \times \text{area of cross section} \\ \text{Section Area } A &= \frac{210 \times 2{,}240}{2{,}970} = 158 \text{ sq. inches} \end{aligned}$$

Section 15 in. $\times$ 11 in = 165 sq. inches, may be adopted.

$$l/h = \frac{25 \times 12}{11} = 27{\cdot}3$$

Backstays.

$$l = 35{\cdot}66 \text{ ft., assume } l/h = 35$$

$$A = \frac{200 \times 2{,}240}{3{,}600 - {\cdot}72 \times 35^2} = \frac{200 \times 2{,}240}{2{,}740} = 165 \text{ sq. inches} = 15 \text{ in.} \times 11 \text{ in.}$$

$l/h = 35{\cdot}66 \times \frac{12}{11} = 39$, rather higher than that assumed, so adopt 15 in. × 12 in.

Bracing Between Front and Back Legs.

This will not be stressed by the tension of the ropes. The stresses will be somewhat indefinite and not large; 10in. x 8in. may be adopted, and bolts 1 1-8in. diam.

Wind Bracing.

Stresses can be calculated in the usual manner if desired. 12in. x 12in. horizontal and 10in. x 8in. diagonals have been adopted. Horizontal members in both the above sets of bracing are supplemented by bolts, so that the main legs are both tied and strutted securely, thus preventing deflection.

The diagrammatic frame has been followed out as closely as constructional considerations will allow.

Overturning Effect in Case III.

The total weight of the frame works out at about 35,000 lbs., not including the weight of pulleys. Vertical through centre of gravity is 45 feet from foot of back-stay. Weight of two pulleys 10ft. diam. and supports about 3 tons or 6,720lbs.

Pull down shaft = 6·5 tons = 14,460 lbs. = weight of loaded and empty cages.

Moment of stability about feet of back-stays.

$$= 35{,}000 \times 45 + 6720 \times 75 + 14{,}460 \times (75 + 5)$$
$$= 3{,}144{,}800 \text{ ft. lbs.}$$

Overturning moment—

$$= 90{\cdot}5 \times 2240 \times 5$$
$$= 1{,}010{,}000$$

So there is no danger of overturning even under these circumstances.

Stability Against Overturning by Wind.

The wind will have its greatest overturning effect when it strikes the frame on the side. Assuming that the legs are not fastened to the foundations, the overturning moment is resisted by the weight of the frame and the total vertical component of the tensions of the ropes. With regard to the intensity of the wind pressure for which the frame must be stable, it is evident from an investigation of certain frames already erected, given later, that these frames are not usually designed to resist the extreme values usually assumed in designing structures of an engineering character. Nevertheless, the author is unaware of any case of a head frame having been overturned by the wind, though they are often of great height and built in very exposed situations.

The Board of Trade rule for important bridges in exposed situations is that they shall be designed for a pressure of 56lbs. per square foot of exposed area. The velocity corresponding to this may be found from the formula (from "Theory and Practice of Modern Framed Structures,"—Johnson, Bryan, and Turneaure).

$$P = \cdot 004V^2$$

where P = pressure in lbs. per sq. ft.
V = veloc. in miles per hour.
For P = 56   V = 118·4 miles per hour, *i.e.*, a very violent hurricane.

A common practice used in calculating the normal pressure on roofs is to take the pressure on a vertical surface as between 40 and 50lbs. per sq. ft. For 45lbs. per sq. ft. V equals 100 miles per hour, still a violent hurricane.

The head frame under consideration will be calculated for a pressure of 30 lbs. per sq. ft., for this V equals 86.6 miles per hour. This would still be of hurricane violence and should be amply sufficient.

If the velocity be that of a violent gale, say, 60 miles per hour, the pressure equals about 14lbs. per sq. ft., and it is unlikely that the pressure will much exceed this value except in very exposed situations. Head frames, too, are generally more or less sheltered by mine buildings.

The exposed area of the frame as seen in side elevation comes to about 450 sq. ft. Total exposed area equals twice this amount since the leeward side also resists the wind; equals 900 sq. ft.

$$\text{Total wind pressure} = 900 \times 30$$
$$= 27{,}000 \text{ lbs.}$$

Centre of pressure is 29.5 ft. above the ground.

Therefore the overturning moment about line joining feet of front and back leg on leeward side

$$= 27{,}000 \times 29\cdot 5$$
$$= 800{,}000 \text{ ft. lbs. (nearly)}$$

The tension in the ropes may be taken when the cages are resting on the keeps and equals the weight of 2000ft. of rope altogether. Vertical component of tension in sloping rope equals 2.1 tons.

Total vertical component = 3 + 2·1 = 5·1 tons.
Weight of two pulleys, &c. = 3 tons.
Weight of structure = 35,000 lbs.
Total vertical force = 53,150 lbs.
= 53,000 (nearly)

This will act along the centre line as seen in end elevation.

Distance between legs at top equals 8.5 feet. Spread or batter given in common practice varies from 1 in 6 to 1 in 10. Take 1 in 8.

Therefore the distance between feet of posts equals 27.25 fee. Leverage of weights equals half this amount, therefore the moment of stability $= 53{,}000 \times \frac{27 \cdot 25}{2}$

$= 724{,}000$ ft. lbs.

This is less than the overturning moment, so that with this pressure the frame would be overturned unless the feet of the posts were bolted to the foundations.

With a spread of 1 in 7 the moment of stability equals 800,000 ft. lbs. nearly.

The frame shown has a spread of 1 in 8, so the feet of the posts should be bolted to the foundation.

In this connection the author has made approximate calculations of the stability of three frames illustrated in the technical journals with the same assumptions as to weight of material, loading and wind pressure.

Gold Coin Frame, Cripple Creek.

(Eng. & Min. Journal, March 7, 1903).

A = Exposed Area = 495 × 990 sq. ft.
P = Total Wind Pressure = 990 × 30 = 29,700 lbs.
H = Height of Centre of Pressure = 35·5 ft.
O.M. = Overturning Moment in. ft. lbs. = 29,700 × 35·5 = 1,060,000 ft. lbs.
W = Total Vertical Force, lbs. = 45,000 lbs.
S = Spread = 26 ft.
M.S. = Moment of Stability, ft. lbs. = 780,000 lbs.

Stratton's Independence, Cripple Creek.

(Eng. & Min. Journal, March 7, 1903).

A = 900,	P = 27,000,	H = 27
O.M. = 729,000,	W = 35,700,	S = 24
M.S. = 428,000		

Kanopolis, Mississippi Valley.

(Eng. & Min. Journal, July 14, 1904.

A = 660	P = 19,800	H = 48
O.M. = 950,000	W = 42,000	S = 40
M.S. = 840,000		

It will be observed that in none of the above cases would the frame be stable with a wind pressure of 30lbs. per sq. ft. unless the legs were fastened down to solid foundations.

Constructional Details.

Posts should be accurately fitted together with mortice and tenon joints, which should receive a good coat of white lead before fitting. The centre lines of the front legs and back-stays should be made to as nearly as possible intersect at the centre of the pulley. The feet of the legs may be supported in cast iron shoes and strap-bolted to concrete blocks. To retard decay due to moisture collecting in the shoe, it is usual to fill them with pitch before stepping the legs. Possibly it would be quite as satisfactory to provide efficient drainage and ventilation.

In "The Mechanical Engineering of Collieries," by Campbell Futers, a formula is given for determining the sizes of the main legs, which, he states, agrees well with practice. The wood used and the position of back-stays is not stated.

The formula is

$$S = \sqrt[3]{\frac{W H^2}{8}}$$

Where S = side of square section of main legs in inches.
W = working load on winding rope due to rope, cage and chains, etc., in tons.
H = height of structure, in feet, from ground level to centre of pulleys.
Backstays = $\frac{5}{9}$ section of front legs, and rectangular in section in proportion of 3 to 4.

Applying this to the above case we have—

$$S = \sqrt[3]{\frac{8 \times 75^2}{8}} = 17{\cdot}75 \text{ inches}$$

i.e., front leg is $17\frac{3}{4}$ feet $\times$ $17\frac{3}{4}$ feet
Backstay cross-section $= \frac{5}{9} \times 17{\cdot}75^2 = 175$ sq. inches
$= 15$ in. $+ 12$ in. (nearly)

The front legs come out much bigger by this formula than that shown to be necessary for the worst possible case, while the section for the back-stays is exactly that adopted.

In the foregoing calculations, the practice has been followed of being well on the safe side of any uncertainty as to strength of material or intensity of loading.

It might appear to some, for instance ,that Case II. is so unlikely as to be unnecessary to consider, or that, at any rate, a lower factor of safety might be adopted. If this case be disregarded, then Case Ib will produce the maximum stresses. If a factor of safety of 2.5 be adopted for Case II., instead of 3.5 as above, the breaking strength for each front leg would be

$$\frac{2{\cdot}5\ (112{\cdot}5 + 5)}{2} = 147 \text{ tons, say } 150 \text{ tons.}$$

instead of 210 tons as adopted.

Similarly for each back-stay

$$2{\cdot}5 + \frac{112{\cdot}5}{2} = 136 \text{ tons, say } 140 \text{ tons}$$

instead of 200 as adopted.

For Case Ib the loads are

$$\frac{(16{\cdot}9 + 5)\ 15}{2} = 164 \text{ tons}$$

for each front leg, and

$$\frac{16{\cdot}9 \times 15}{2} = 126 \text{ tons for each backstay}$$

Say, 165 and 135 tons respectively, making allowance for extra load due to weight of structure, etc., as mentioned above.

Under these conditions, the legs should be proportioned for a breaking strength of 165 tons for each front leg and 140 tons for each back-stay.

Again, in Johnson's formula for columns.

$3600 - {\cdot}72\ (l/h)^2$ = breaking strength in lbs. per sq. inch.

3,600lbs. per sq. inch., the maximum value, is the crushing strength for green timber or timber that is wet-through after seasoning. For Oregon with 12 per cent. moisture, the average crushing strength is nearly 6,000lbs. per square inch (Johnson's "Material of Construction"). Moreover, as mentioned, this formula gives the strength for columns with unfixed square ends. The two end panels of the main legs might farily be regarded as fixed at one end and the intermediate panels at both ends, as the material is continuous, except for the necessary mortising for the ends of struts and bolt holes, and is securely prevented from deflecting by bolting and strutting. The mortise and bolt holes, being at the ends of the columns, do not reduce their strength to any extent.

If jarrah had been used, and the legs calculated for loads of 165 and 140 tons, the scantlings would be as follows:—

Jarrah columns for $l/h = 35$, with 12 per cent. moisture they have a crushing strength 5,500 lbs. per sq. in.

Deduct one-third for reduction in strength due to becoming wet or being unseasoned —

(From recent Government tests of West Australian hardwoods, by G. A. Julius, B.Sc.)

= 5,500 – 1,600 = 3,600 lbs. per sq, inch (nearly)

For front leg cross-sectional area

$$\frac{163 \times 2{,}240}{3{,}600} = 103 \text{ sq. inches}$$

$11 \times 10 = 110$ sq. inches would suffice.

For back leg, taking $l/h = 40$, the strength for 12 per cent. moisture may be taken as 4,500lbs. per square inch, and when wet as 3,000lbs. per square inch.

$$\text{Section required} = \frac{140 \times 2{,}240}{3{,}000} = 105 \text{ sq. inches}$$

therefore $11 \times 10 = 110$ sq. inches would do for backstays, also.

It would not be advisable to reduce the scantlings much below this, even if strong enough, as the rigidity would be liable to suffer, and it must be remembered that rigidity, as well as strength, is essential.

With regard to the height, it will be found by an inspection of drawings of head frames already erected at metalliferous mines that the allowance for overwinding is not, as a rule, nearly equal to one revolution of the winding drum; probably about half that amount would represent common practice. As a rule, the rate of winding is lower than that usual for collieries, so that a reduction in this respect is justifiable. The distance from the detaching platform to the centre of the pulley is often less than the 10ft. shown in the design submitted. Taking this as 7ft., and the allowance for overwind as half a revolution of the drum, the total height above the landing platform would be
instead of 50ft. as shown.

$$9 + \frac{31{\cdot}4}{2} + 7 = 32 \text{ ft. (nearly).}$$

A detail is given of the head-gear showing the method of supporting the plummer blocks. At the sides they are arranged directly over the front legs. The inner ones are attached to heavy horizontal pieces carried by vertical posts supported by a strut between the front legs. At the ends these horizontals are bolted to crosspieces, and strutted off the main legs. The struts and vertical posts are securely braced to give lateral rigidity.

It will be observed that the centre lines of front and back legs intersect at the centre of the pulley axle, so that no bending moment is developed. Access to the head-gear could be obtained by constructing steps with a hand rail up one of the back legs.