THE DESIGN OF HEAD FRAMES FOR MINES.

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The main objects of a head frame, or poppet head, are to support the winding pulley firmly and to guide the cage above the surface to the discharging stage.

Points which should be attended to are:—

(1) That the pulleys are rigidly supported; the frame being amply strong and rigid for ordinary winding.
(2) That the frame shall be strong enough to survive any accidents which may occur.
(3) That the frame is stable against overturning under the worst conditions as to wind or loading.
(4) The design must be adapted to local circumstances.
(5 It must be durable.
(6) The cost shall be as low as is consistent with fulfilling other conditions.

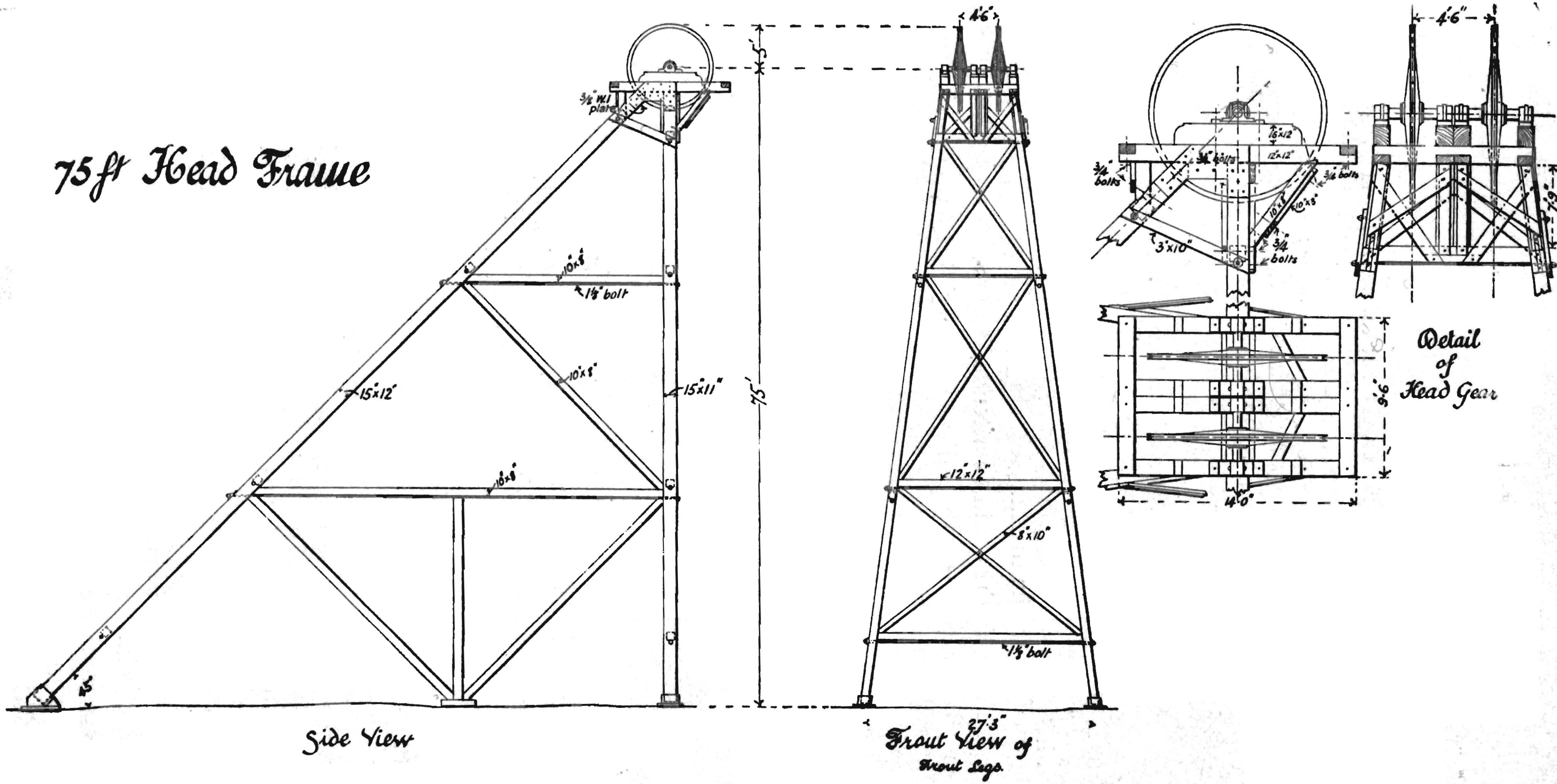
Cage Framing and Pulley Supports.

The head frame consists of two portions: the frame proper, which supports the pulleys, which must be designed to resist all stresses induced by winding; and the cage framing, which really forms a continuation of the shaft above ground, and serves to guide the car above the ground. The head-gear may be designed either with the pulley supports independent of the cage framing, or the two may be combined.

If the separate system be adopted, the cage framing must be made strong enough to resist stresses due to supporting the weight of the loaded cage when resting on the keeps and the weight of guide ropes—if such be used. It may also have to bear the shock due to the cage, when overwound and being detached, falling back and being suddenly arrested by the automatic gear.

In the combined system, the pulley supports must be designed to resist stresses due to winding and those above-mentioned.

75 ft Head Frame



The separate system admits of the cage framing being more compactly designed to fit the cage than is the case with the combined method. The framing is vertical, and is supported on heavy sole pieces placed round the top of the shaft. In this system, the stresses are more definite and more readily ascertained.

Height.

This is one of the first points to be settled, and will depend chiefly upon the situation and particular requirements. It will be necessary to raise the ore above the top of the mill ore-bins, and the height necessary will, of course, be less if there be a slope from the shaft to the mill. There should also be room for dumping waste material.

When the height of the discharging level above the surface has been settled, other considerations will decide the height above that level. This height must be sufficient to allow of a certain amount of overwind before the detaching hooks come into operation.

In the best practice with quick winding, it is usually recommended that this be made equal to one revolution of the winding drum. The pulleys should be fixed sufficiently above the detaching hook bell platform to allow the cage to be lifted out of the catches without the rope capping coming on to the sheave of the pulley.

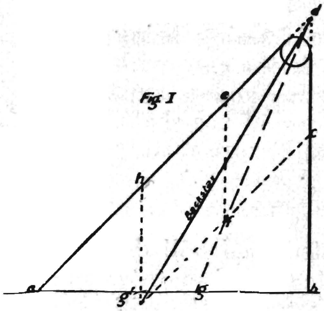
The height will then be made up as follows:—Height above surface to discharge level plus the height of cage and attachments plus the circumference of winding drum plus the distance necessary from detaching platform to centre of pulley.

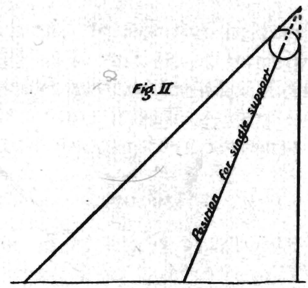
Having determined the height, and whether the frame shall be on the separate or combined system; the members necessary, and their best arrangement must be considered. To do this satisfactorily, a thorough investigation of the forces which will or may, come upon the structure, is necessary.

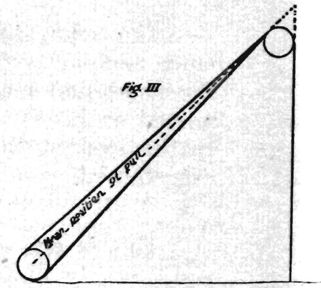
Assuming that the separate system is adopted, and considering only the pulley supports, there are usually two front legs, vertical in side elevation, and two back-stays sloping back towards the winder to prevent the front legs being pulled over backwards.

The best position of these back-stays is a matter upon which opinion differs. Some designers arrange them parallel to the sloping portion of the winding-rope; others bisecting the angle between vertical and sloping ropes; and others, the majority, in a position intermediate between those two. In some text-books the question is disposed of by giving a rule that the position is determined as follows:—

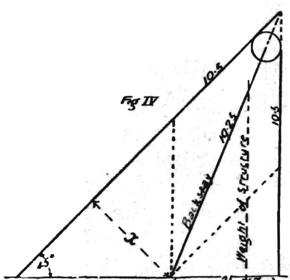
The pull on the vertical and sloping ropes is the same; therefore, if we set off distances dc equal to de (Fig. I.) to equal







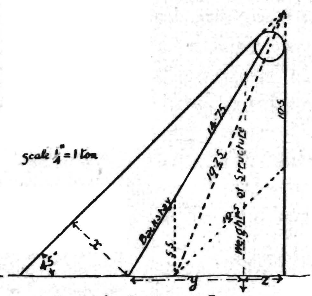
Common Rule for Position of Backstay



Stress in Backstay

when parallel to resultant for working load

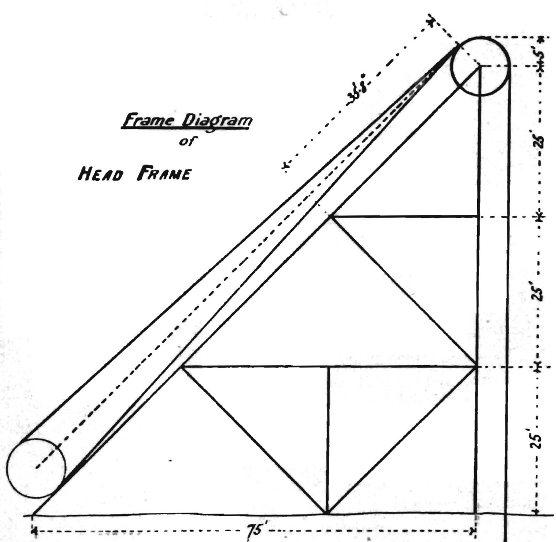
scale 1/4" = 1 ton

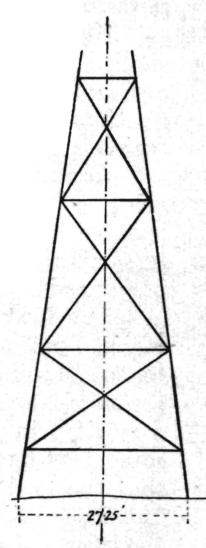


Stress in Backstay & Front Leg

for working load when Backstay is arranged according to common rule.

Frame Diagram of HEAD FRAME





the pull on the rope, then **df** is the resultant, and, theoretically, the position of the back-stay is given by **dg**. However, to provide against contingencies such as the over-winding of the cage, set out **dh** equal to 2 **dc** and take **dg′** the direction of the resultant under these conditions, as the position of the back-stay. Theoretically, for ordinary working, only one support is necessary, arranged so as to bisect the angle between the vertical and sloping ropes, as is adopted usually for whips (Fig. II.). This would be unstable in a large structure, and so a vertical support becomes necessary. If the foot of the back-stay lies between the theoretical position (i.e., bisecting the angle between the ropes) and the shaft, the resultant of the tensions lies outside the base, and there is a tendency for it to be overturned backwards. If it lies between the theoretical position and the winding drum, some of the weight is thrown on the vertical support or front legs.

If the direction of the resultant were invariable and of known amount, there is no doubt that the best position for the back-stay would be along the line of the resultant. It is possible, however, that accidents may alter its position.

Loading.

The principal forces will be the tensions in the winding ropes. If there be two pulleys with one rope passing under and the other over the drum, the greater tension will be in the hoisting rope, the lowering rope being comparatively slack. The mean position of the pull of the sloping ropes, since each rope is alternately hoisting and lowering, is along the line through the centre of the winding tangent to the pulley (Fig. III.) there will also be the vertical pull down the shaft. The maximum pull will be the sum of the tensions in the two ropes.

For ordinary working, the tension in the ropes will be due to the dead weight of loaded cages, chains and rope, friction against guides and in pulley-bearings, and the force necessary to accelerate the cage from rest to the maximum speed of winding in a certain interval of time. These are the legitimate working loads. Momentary stresses may, however, much exceed these, the commonest being the case where the rope is slack when winding begins. With careless winding the result will be a jerk, producing stresses whose magnitude it is difficult to estimate, but which might easily double the ordinary stress.

Of these loads, the weight of cage, rope, etc., may be considered dead load; that due to acceleration (and retardation) as live load. The shock due to slack rope, besides producing higher stresses, would be more destructive on account of the fact well known that loads suddenly applied have a worse effect than those applied steadily. Hence, an allowance should be made for dynamic effect. To the above loads must be added the weight of the structure itself.

It is necessary to consider, however, not only the commonly occurring stresses, but the worst possible case.

The greatest possible tension which may be developed is equal to the breaking strength of the rope. This tension might be induced by some such accident as the cage suddenly sticking in the shaft owing to some obstruction when travelling at a high speed, with the result that the hoisting rope is snapped. The engine would itself be incapable of exerting a steady pull equal to this amount, but engine pull plus stresses produced on account of the inertia of the parts, rope, pulleys, etc., might reach this value. The total greatest possible tension on the vertical and sloping ropes may then be taken as equal to the breaking strength of one rope plus the tension on the lowering rope. To this must be added a certain percentage to allow for dynamic effect, say, 25 per cent. Another possible accident is when the cage is overwound and the detaching hook fails to act. The resultant pull would then be practically along the line of the sloping rope, and its limiting value will be equal to the breaking strength of the hoisting rope plus the tension on the lowering rope. The only pull down the shaft would be the tension on the lowering rope. This last case would be that having the greatest tendency to overturn the frame.

Wind pressure must also be provided for as tending to overturn the structure sideways. This tendency is met by giving the legs a spread or outward batter.

Stresses will also be induced owing to the inequality of the tensions in the hoisting and lowering ropes, tending to twist the frame.

If machinery such as rock-breakers be mounted on the frame, the resulting vibration will have a destructive effect upon joints and fastenings.

In the following calculations the practice of taking the nearest round number has been followed, since the whole of the estimates of loading, strength of materials, friction, etc., are of necessity only approximations, and are covered by the factors of safety adopted, so that it would be useless to attempt to state them with apparent minute accuracy by carrying them to several places of decimals.

For purposes of illustration, let the following data be assumed:—

Depth of Shaft	2,000 feet
Rate of Wimdings	1,000 feet per minute
Weight of Cage, Chains and Loaded Trucks ...	4 tons
Weight of Cage, Chains and Empty Trucks ...	2·5 tons
Weight of 2,000 feet of Rope	3·0 tons

TENSIONS ON ROPES.

Lowering Rope.—

Weight of Cage, Chains and Empty Trucks ...	2·5 tons

Hoisting Rope.—

Weight of Cage, Chains and Loaded Trucks ...	4·0 tons
Weight of 2,000 feet of Rope	3·0 tons
Add 12 per cent. for friction	·84 tons
Total	7·84 tons

To this must be added the force necessary to accelerate the loading cage to a speed of 1000 feet per minute. Kerr ("Practical Coal Mining") states that the time required to reach full speed from rest equals 1-7th total time of hoist. Taking time of hoist as two minutes, time required to reach full speed $= \frac{120}{7}$ seconds.

$$\text{Velocity} = \frac{1000}{60} \text{ ft. per sec.}$$

$$\text{Acceleration} = \frac{\text{Veloc.}}{\text{Time.}} = \frac{1000}{60} \times \frac{7}{120} = \cdot 97 \text{ ft. per sec. per sec.}$$

$$\text{Accelerating force in tons} = \frac{\text{Weight in tons} \times \text{acceleration}}{32}$$

$$= \frac{7{\cdot}84 \times {\cdot}97}{32}$$

$$= {\cdot}236 \text{ tons}$$

$$= {\cdot}25 \text{ tons (say)}$$

Total load on hoisting rope therefore is

$$7{\cdot}84 + {\cdot}25 = 8{\cdot}09 \text{ tons, say } \underline{\underline{8{\cdot}1}}$$

Taking a factor of safety for the rope of 10, then the breaking strength required equals 8.1 x 10 equals 81 tons.

Best plough steel rope, 4¼in. circumference, has a strength of 81 tons, and weighs 18lbs. per fathom.

Actual weight of 2000 feet of rope is therefore

$$\frac{2000 \times 18}{6 \times 2240} = 2{\cdot}7 \text{ tons.}$$

i.e., ·3 tons less than that assumed.

Take 8 tons as the total load on the hoisting rope as near enough, and on the safe side.

Total pulls for vertical and sloping ropes therefore = 8 + 2·5 = 10·5 tons each.

As before mentioned, the tension calculated above may rise much above this value if the rope be slack when hoisting commences. Dynamo-meter tests (see "Mines and Minerals," May, 1904) have given the following results:—

		Stress by dynamometer.
Empty Cage lifted gently	no slack	4,030 lbs.
,, ,,	2½in. slack	5,600 lbs.
,, ,,	6in. slack	8,950 lbs.
,, ,,	12in. slack	12,300 lbs.
Loaded Cage and Trucks lifted gently,	no slack ...	11,300 lbs.
,, ,, ,,	3in. slack ...	19,025 lbs.
,, ,, ,,	6in. slack ...	24,625 lbs.
,, ,, ,,	9in. slack ...	26,850 lbs.

It appears, therefore, that the momentary tension with 6in. slack is about twice the tension due to the weight of the cage alone. Starting from this assumption, we have as the maximum tension on the hoisting rope, considering the effect of 6in. slack:—

$$\begin{aligned} &2\,(\text{weight of loaded cage and trucks}) + \text{weight of rope} + \text{friction} \\ &= 2 \times 4 + 2{\cdot}7 + {\cdot}84 \text{ tons} \\ &= 11{\cdot}54 \text{ tons} \end{aligned}$$

Since this is accompanied by shock, add 25 per cent. for dynamic effect $= 2{\cdot}9$ tons.

$$\text{Total} = 11{\cdot}54 + 2{\cdot}9 = 14{\cdot}44 \text{ tons.}$$

The factor of safety for the rope need not be so high in this case, because this tension is only occasional, and due allowance has been made for dynamic effect, say 6.

$$\begin{aligned} \text{Breaking strength required} &= 14{\cdot}44 \times 6 \text{ tons} \\ &= 86{\cdot}64 \text{ tons} \end{aligned}$$

Cradock's improved plough steel rope of same thickness and weight as that previously taken has a strength of 88 tons, and may be adopted. Total pulls for this case $= 14{\cdot}44 + 2{\cdot}5$
$= 16{\cdot}9$ tons (nearly).

Having obtained the breaking strength of the rope required, we may proceed with the design of the structure.

Factors of Safety.

A large factor of safety should be provided against the ordinary working loads, i.e., in the case under consideration when the total pull equals 10.5 tons, in designing the members of the structure. Unwin gives 20 as the best value to adopt for a timber structure subjected to varying loads accompanied by shock and vibration. Hence, the breaking strength of the front and back stays should be 20 times the stress produced by the maximum working tensions on the ropes, and the weight of the structure itself.

For the case of the occasional tension produced by slack rope (16.9 tons in this case), a smaller factor, say, 15, may be adopted.

For cases of extreme loading, such as those produced by the hoisting rope being snapped, a much lower value may reasonably be adopted, say, 3 or 4, since it is improbable that they will ever occur, and if they should, it is only necessary that the structure should survive without serious injury.

In order that the frame may be safe against overturning under the worst condition, i.e., when the resultant pull is nearly parallel to the sloping rope and equal to the breaking strength of the rope, it is sufficient that the moment of the weight of the structure about the line joining the feet of the back-stays shall be equal to the overturning moment of the resultant pull about the same line.

For safety against overturning by the wind sideways, the overturning moment of the pressure due to the most violent wind probable about the line joining the feet of the front and back stay on the leeward side must not exceed the moment of stability of the weight of the structure and its loads, about the same line.

Three cases of the stresses due to winding may be investigated.

I. (a) Strength and stability for working loads, i.e., for pull on ropes equals 10.5 tons. Factor of safety equals 20.

(b) Or, if the max. pull on the hoisting rope due to 6in. slack rope be regarded as the working load for a pull equals 16.9 tons. Factor of safety equals 15.

II. When pull on hoisting rope equals its breaking strength, add 25 per cent. for dynamic effect and add tension in lowering rope.

$$88 + 25 \text{ per cent of } 88 + 2{\cdot}5 = 110 + 2{\cdot}5 = 112{\cdot}5 \text{ tons.}$$

Factor of safety may be taken as 3.5.

III. When pull on sloping rope equals breaking strength.
Total pull on slope equals 88 plus 2.5 equals 90.5 tons.
Total pull vertically equals weight of full cage plus tension on lowering rope.

$$= 4 + 2{\cdot}5 = 6{\cdot}5 \text{ tons.}$$

If the stresses be calculated for this case, dynamic effect should be allowed for. They will be less than in Case II., so it is unnecessary to do so. Overturning moment is a maximum in this case.

In the accompanying table will be found the stresses produced, and the breaking strength required of the front legs and back-stays for Cases Ia and b and Case II., for different positions of the back-stays. The method of obtaining the stresses graphically in case Ia is illustrated in Figs. IV. and V.; stresses produced by tensions in cases Ib and II. are directly proportional to the amount of the tensions.

Method of obtaining the overturning moment is illustrated.

When the back-stays are arranged parallel to the rope, the total stress in them equals the total tension in ropes, and the total load on the front legs due to the tension of the ropes equals the total tension of vertical ropes.