TECHNICAL NOTE 017

Engineering Safety of Material Hoists – Double Trouble via Pulleys

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Version 01, May 2017

Keywords
Material Hoist, Pulley System, Cable Force, Local Effect, Design Load Cases

Synopsis
A material hoist is a powered-mechanical plant commonly used on construction sites for vertical transportation of construction materials. The cage (or platform) inside the hoist is hung to a cable that runs through a pulley system. The cable is secured to a winch or winding drum at ground level. As part of the package, the design of the material hoist is usually prepared by the hoist supplier or their designer. In a recent RAT design review, the design force for the vertical members of the material hoist was found to be grossly underestimated. It appears that the designer had somehow omitted the doubled load effects caused by the pulley system. For all Chun Wo's projects, the load cases shown diagrammatically on page 02 are required to be considered by the material hoist designer(s).

1.0 Introduction

Incidents of material hoist failure are not uncommon. The failure could be caused by many reasons under different circumstances including during load-testing. As shown in the photos below, the member supporting the pulley failed and one of the vertical members of the material hoist buckled. The reason(s) for material hoist failure could be many, and design inadequacy could be one.

It was discovered in a recent RAT design review that the applied force for the vertical members of the material hoist was grossly underestimated. Details are explained hereinafter.

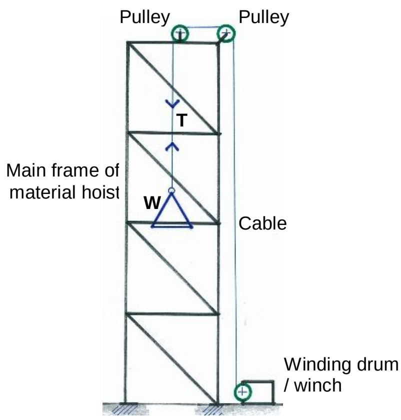

Member supporting the pulley failed


Vertical member of the material hoist buckled

NB –
For structural design of material hoists, various basic load cases have to be considered. This technical note focuses solely on the load effects caused by the pulley system.

2.0 General Arrangement

The simplest form of a material hoist is shown indicatively below. The mast of the material hoist is a laced strut formed using angle or other sections. The weight '**W**' is supported by a cable that runs through a pulley system.



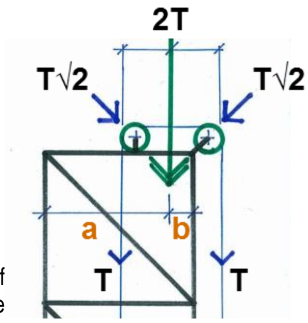
The pulleys are supported at the top end and the cable is secured to a winch or winding drum at ground level.


Member supporting pulleys


Close-up view of a pulley and supporting members

The force '**T**' in the cable is induced by the weight 'W', including a specified 'Safe Working Load' plus the dead weight of the associated structures such as a platform or a cage.

Free body diagram of material hoist and cable



Load cases that must be considered:

i) For a cable force of **T**, the material hoist must be designed, among other load effects, to resist a resultant force of **2T**. The location of the resultant force shall be determined based on the setting out dimensions of the pulleys in relation to the material hoist;

ii) For a cable force of **T**, the members supporting the pulley must be designed, among others load effects, to resist an inclined force resultant of **T√2**.

3.0 Design Force in Vertical Members

3.1 Design Assumption by Material Hoist Designer

It is noted in some design reports that the vertical legs of the material hoist (4 nos in total) have been designed to resist a force that is equal to **0.25T**, ie, each leg of the material hoist shares the cable force equally. The relevant part of the design report is extracted and shown below. In this particular case, for a factored load of 166.3 kN, each leg was designed to resist **42 kN**.

70 x 70 x 8mm angle mast support the loading

Factored Weight of hoist	=	166.3 kN
(included weight of 3" mast, weight of landing platform, wire rope and accessories)		
Compressive force by weight on each leg	=	166.3 / 4
	=	42 kN
Compressive force by wind on each leg	=	17.3 kN

It must be pointed out that the above simplifying assumption ignores the cable load path, causing a very substantial underestimation of the design force in the vertical legs of the material hoist.

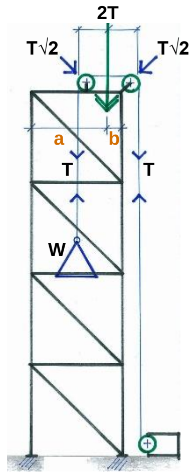
3.2 Load Effects caused by Pulley System

Ignoring any frictional resistance in the pulleys, the cable force caused by the weight 'W' is assumed to be **T**. The material hoist is thus subjected to a resultant force of **2T** acting at a location depending on the setting out dimensions of the pulleys in relation to the material hoist. Also, each pulley is subjected to an inclined force of **T√2**, and therefore the members supporting the pulleys are required to cater for this inclined load effect.

For a factored load of 166.3 kN, ie, **T** = 166.3 kN, the material hoist is subjected to a resultant force of **2T**, ie, **332.6 kN**. The sharing of this force by the vertical legs depends on the dimensions of 'a' and 'b'. For instance, if the ratio of a:b is 5:1, the two vertical legs next to the winch or winding drum will take the following share of the resultant force:

$$\left(\frac{5}{5+1}\right) \times 332.6 = \mathbf{277.2\ kN}$$

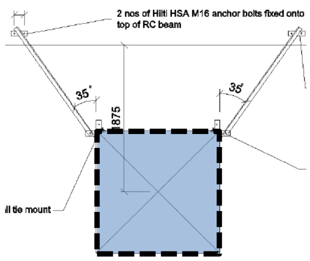
Hence, each leg shall take 138.6 kN. Comparing to the equally shared design force of 42 kN, the material hoist was designed to cater for only **30%** of the demand!



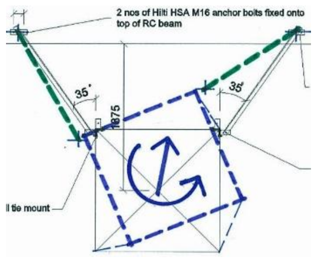
4.0 Other Observations

4.1 Effectiveness of Lateral Restraint

It is noted in many instances that lateral restraints to the material hoist mast are provided in the arrangement (plan view) shown below. In essence, the members providing the lateral restraint are not triangulated, meaning that the mast can translate and rotate freely without stretching any restraint members. As such, the lateral restraint is not effective.

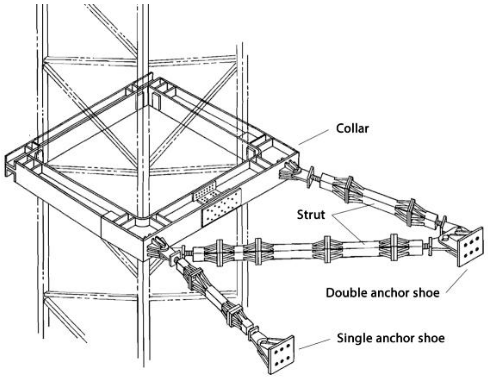


Ineffective lateral restraint (without triangulated members)

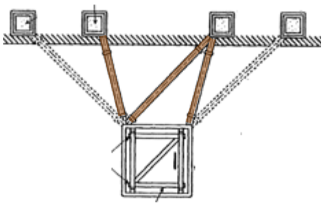


Material hoist is free to rotate and translate on plan

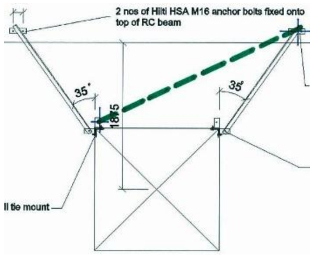
Triangulated lateral restraint system for a tower crane mast



When compared to the lateral restraint to a tower crane mast, it becomes apparent that an additional member is required to be installed to enhance the restraint effectiveness.



Triangulated lateral restraint (orange in colour) to a tower crane mast

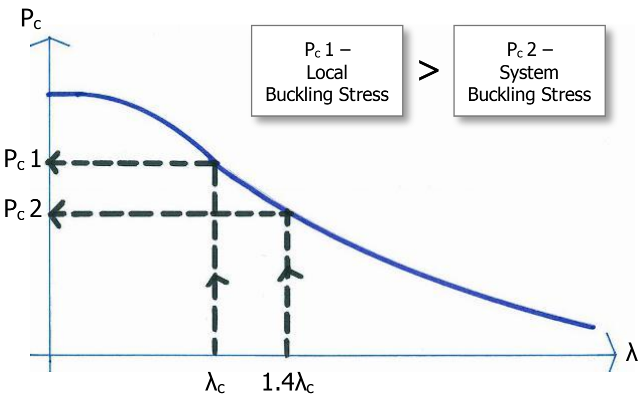


Additional member (green in colour) should be added to restrain the material hoist mast

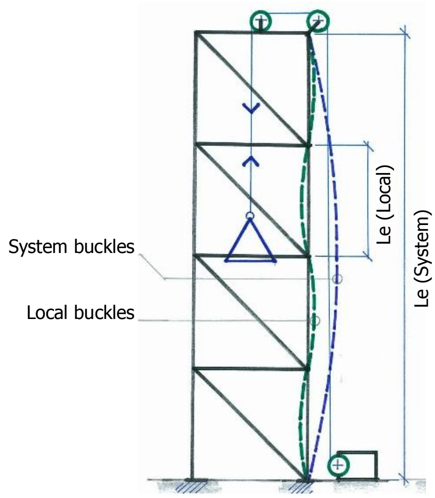
4.2 Local and System Buckling

According to the Code of Practice for Structural Use of Steel 2011, the mast of the material hoist should be structurally designed as a **laced strut** as per Cl. 8.12. One of the key requirements is that the spacing of lacing should so be arranged such that local buckling failure of the main component is prevented to happen before system buckles. This is enforced by the following clause in the code:

Cl. 8.12.1 g) The slenderness λ_c of the main components about their minimum radius of gyration between consecutive points where the lacing is attached should not exceed **50**. If the overall slenderness of the system is less than 1.4 λ_c the design should be based on a slenderness of $\mathbf{1.4\lambda_c}$.



The requirement on the member and system slenderness is found not followed by the designer(s), causing potential local buckling failure of hoist members.



NB –

This technical note covers only the engineering safety aspects of material hoists. There are other statutory, health and safety, and testing requirements which need to be dealt with sufficiently. Please feel free to discuss with the Technical Department regarding your particular issues regarding the use of material hoists.

- End -

This technical note is for internal circulation only.
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