ELEVATOR HOISTWAY EQUIPMENT: Mechanical and Structural Design, Part I

by George W. Gibson

Learning Objectives

After reading this article, you should:

- Have developed a basic understanding of the structural systems within the hoistway.
- Understand that the two most important characteristics of any structure are its strength and rigidity.
- Have learned that the most important piece of information needed to serve as the basis for the mechanical, structural, and electrical design of an elevator system is the specific use intended by the customer.
- Have developed a basic understanding about the loads acting on the elevator car structures and the effects of these loads on the structural performance of the elevator.
- Understand the construction of corner-post elevators, and the causes of the platform sagging at one of its corners.
- Have developed a basic understanding about the functions of the guide rails, the forces which act on them and the effects of these forces.

1. INTRODUCTION:

The material in this article was originally presented in a 2 part series by the author in ELEVATOR WORLD in August and November 1982, and has been updated to reflect the latest requirements in the ASME A17.1 Safety Code for Elevators and Escalators and industry practice. The updated articles explain the technical basis for the design of elevator mechanical and structural equipment in a qualitative way in order that the reader gain a basic understanding of the mechanical and structural systems within the hoistway and at the interface between the hoist ropes and driving machine, rather than dwelling on the quantitative aspects with a huge array of equations.

Safety equipment, such as buffers, governors and car and counterweight safeties were discussed in another paper by the author, "Stopping Capability of Safeties" (ELEVATOR WORLD, July 1988). The ASME A17.1 Safety Code for Elevators and Escalators, an American National Standard, including the latest supplements, is used as the common denominator for certain design limits. There may well be other criteria peculiar to specific manufacturers which may be more stringent than the ASME A17.1 Code, or certain design parameters may be applied where there are no Code requirements. This latter point is related to the engineering and commercial philosophies of the individual companies, sometimes referred to as *"engineering best practice"*.

Much of this article will refer to elevator equipment in the general sense since specific product designs vary somewhat from company to company.

2. GENERAL DISCUSSION OF STRUCTURES:

Hoistway structures comprise all the load-bearing structures found in the hoistway; namely, Suspension (Hoist) Ropes, Car frames, Bracing, Platforms, Cabs, Guide Shoes and miscellaneous supports, all of which are on the moving elevator system, including the counterweight. The hoistway fixed structures include all load-supporting systems found in the

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hoistway, such as, overhead beams, guide rails and brackets, and pit steel.

By way of introduction, a brief explanation of some of the basic concepts of structures is in order.

First of all, the basic function of any structure, be it a simple beam or complex structural frame, is to support the loads imposed on it. Every object on earth is subject to the force of gravity and it is this force which produces the load, or force, acting on the supporting structure.

Throughout this article, the terms "loads" and "forces" are used freely. It should be understood that these terms are relatively synonymous in the Imperial System of measurements, where the dimensional units are in lbs, kips, etc. In the Metric (SI Units) System, the loads, which derive from the physicality of the objects, are usually referred to as Masses, expressed as kg. This article will focus on the Imperial System.

A basic law applying to structures is Newton's Third Law which states that, "for every action, there is a reaction." The "action" is the force, or load; the "reaction" is the effect that the supports exert on the beam or frame.

Since every structure is made from materials that possess elastic properties, the structure will undergo deformations due to the loads imposed upon it. In the case of the simple beam with a single concentrated load, P, acting at midspan, as shown in Figure 1, the "action" is the load, P. The "reactions" are P/2 at each support. The solid line represents the position of the beam in its originally unloaded position. The dashed line represents the deflected mode of the beam due to the load, P.

In order to determine the strength of the beam and how much it deflects, we must know the Bending Moments in the beam. Simply stated, a Bending Moment, M, is the product of a force times a distance. In the case of the simple beam shown in Figure 1, the maximum bending moment, M, exerted on the beam is equal to the reaction, P/2, times the distance to the load, L/2, which equals PL/4. This is seen as follows:

$$M = \left(\frac{P}{2}\right)\left(\frac{L}{2}\right) = \frac{PL}{4}$$

Due to this bending moment, the upper face of the beam tends to shorten or compress, and the lower face stretches, or elongates. In this process, internal stresses are set up in the beam. In Figure 2 the beam is shown so that its depth of section is seen as well as the shortening and elongating of beam faces.

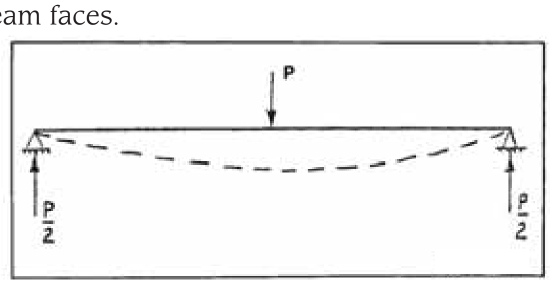

Figure 1

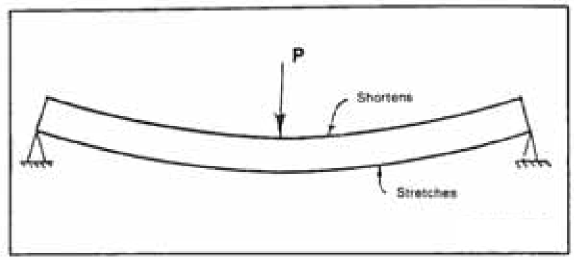

Figure 2

The stresses set up in the beam are a measure of this shortening and stretching of the beam's fibers, and it is this criteria which we use to evaluate the strength of the beam.

All structural materials have what is called an "Ultimate Strength." This is the value of the stress when the structural material will fail, ignoring the Theory of Plasticity. When we design our structures, we limit the allowable stress to a value far lower than the ultimate strength of the material. The ratio of the Ultimate Stress to the Allowable Design Stress is called the Factor of Safety. This term is defined in the ASME A17.1 Code. This factor of safety is generally arrived at by considering the use to which the structure is put, whether human life is involved, manufacturing and fabrication errors, tolerances, etc., and is usually spelled out in local building and elevator codes. All of the structures used in the elevator system must conform to the requirements of the *ASME A17.1 Safety Code for Elevators and Escalators*, latest edition.

In addition to the strength requirements of the structural member, there is the requirement of rigidity. As noted in Figure 1, the beam deflects under the action of the load and we must set some limits on this deflection; otherwise while the beam must be strong enough to resist the load, it might, on the other hand, be too flexible and act like a spring.

Many of the structures encountered in our elevator system cannot be treated in the simplest form of a beam, however. In these instances, the member may be part of a frame. A frame, by definition, consists of a few, or many, structural members rigidly connected to each other at joints. In order that the subsequent discussion of car frames be readily understood, a few basic concepts about Frames will be presented here.

Consider the very simple case of a 3-member structural frame, as shown in Figure 3, consisting of two vertical columns anchored to the ground at their lower end and connected to a horizontal beam resting on top of them, and rigidly connected at the joints. As we did before with the simple beam, let us put a load, P, on the center of the horizontal beam.

As noted above, we are dealing with elastic members, and consequently, under the action of the load, the cross beam will deflect, as noted in Figure 3.

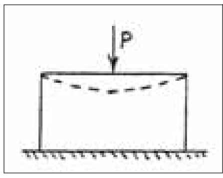

Figure 3

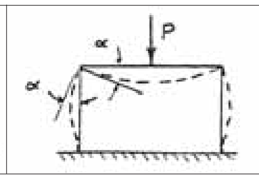

Figure 4

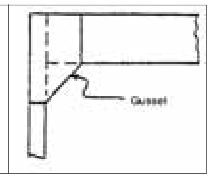

Figure 5

In order that the frame be stable and not collapse, the joints must be rigid; which means that whatever angle exists between frame members before loading, must also exist after loading. From Figure 3, it can be seen that as the cross beam deflected, it also underwent some rotation at its ends. Therefore, in order that the same angle between the column and beam remain at right angles (90°), as in this case, the upper ends of the columns must also rotate the same amount as the beam. This final deflected mode for the frame is shown in Figure 4.

This induced rotation at the joints causes a bending moment to be set up in the columns. Not only must the columns be designed to withstand this bending moment, but also the joint connection, whether it is welded or bolted, must be strong enough to resist the bending moment induced at the joints.

This is called a Continuity Condition of Structures, and exists only when the joints are rigid. This joint rigidity is usually accomplished by putting a gusset plate at the joint and fastening it securely to adjacent members by means of bolts, rivets or welds, or any combination. Figure 5 shows such a detail.

3. ELEVATOR LOADING CONDITIONS:

3.1 Elevator Usage:

When a customer buys an elevator, he/she will have a specific use intended. This use is the most important piece of information about the elevator installation, and it will serve as a basis for the designs; mechanically, structurally and electrically.

The most important single factor which influences the design of the car frame, platform and guide rail is the method of transfer and distribution of loads on the elevator.

Elevator use or Class of Service, as specified in ASME A17.1 Rule 2.16.2.2, may be broken down as follows:

A. Passenger Service – wherein the elevator is used primarily to carry people.

B. Regular Freight Service – covers elevators loaded with small packages, cartons, etc.; however, no single piece of freight can weigh more than 25% of the rated load. The term, *Rated Load*, is defined in the ASME A17.1 Elevator Safety Code as: *"The load that the equipment is designed and installed to lift at the rated speed"*. Some manufacturers refer to this term as: *Duty Load or Contract Load*.

The ASME A17.1 Elevator Safety Code refers to Cases A and B, above, as Class A loading.

C. Automobile Truck Service – applies to elevators that must carry commercial vehicles in which case no more than 75% of the rated load, distributed between the wheels on the truck, which must be at least 5 feet apart. Refer to Figure 10 for a representation of this loading. However, the wheel load spacing is not less than 5 feet. This is called Class B Loading, as codified in ASME A17.1 Rule 2.16.2.2.2.

D. Industrial Truck Service – applies to elevators that are loaded or unloaded by Industrial, or Fork Lift, Trucks, in which case approximately 80% of the rated load is supported on one axle of the truck and there is at least 30" between wheels on the loaded axle. This is referred to by the ASME A17.1 Code Rule 2.16.2.2.3 as Class C Loading, and is generally the most severe type of loading.

3.2 Car Frames and Platforms – General Requirements:

ASME A17.1 Rule 8.2.2.1 requires that the structural analysis of side-post type car frames and platforms be based on the data and formulas given in Section 8.2.2. The basis for this requirement is that these formulas cover conventional car frames and platforms. For cases where conventional design methodologies are not applicable, the designer can be guided by the ASME A17.1 Code, which anticipates the necessity of departing from conventional codified requirements for engineering calculations.

The opening paragraph of ASME A17.1 Section 8.2 states among other things: *"It is not intended to limit design."*

ASME A17.1 Rule 8.2.2.1 states in the 3rd paragraph:

> *"For cars with corner-post, underslung, or other special car frame and platform construction, the formulas and specified methods of calculation of loads and the resulting stresses do not generally apply and shall be modified to suit the specific conditions and requirement in each case."*

While most structural designers might feel constrained by the requirement which relates to conventional design, more imaginative structural designers can avail themselves of the broader latitude based upon the above. Utilization of contemporary structural analyses afforded by Finite Element Analysis and other modern-day methods are made possible. However, it is important to comply with the 4th paragraph of ASME A17.1 Rule 8.2.2.1 which states, "The maximum allowable stresses and deflections of members of all car frames and platforms shall be not more than those permitted by 2.15.10 and 2.15.11."

3.3 Load-Bearing Structures:

In a completed elevator installation, the only thing visible to a casual observer is the entrance to the car and the car interior, but the observer would certainly notice if the platform floor on which he/she were standing sagged or

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dropped below the landing sill when a load was brought onto it. The cause of the defect might be a weak car frame, or platform, insufficient guide rail supports, or a combination of any, or all, of these defects.

Therefore, in the design of the structural equipment, it is a cardinal rule that, first of all, the structure is made from materials which have elastic properties, and secondly, due to the loads imposed on the structure, it will undergo deformations because of its elasticity. We must be able to predict very accurately, the effect of these deformations.

The four principal load-bearing structures in a traction elevator system are:

A. Suspension (Hoist) ropes.
B. The elevator platform which directly supports any load brought onto the elevator.
C. The car frame, a rectangular structural sling lying in a vertical plane to which the hoist ropes are fastened to the upper horizontal members and the platform is supported at its center by the bottom members. In the case of a hydraulic elevator, the plunger is generally fastened to the underside of the plank channels, as seen in Figure 25.
D. The guide rails, likened to railroad tracks, are mounted vertically in the hoistway, fastened to the building structure, and are contacted by four corner guide shoes attached to the car frame. These provide stability to the elevator car in its vertical travel.

4. PLATFORMS AND BRACING:

The ASME A17.1 Code defines the elevator car platform as: *"The structure which forms the floor of the car and directly supports the load"*. The basic function of an elevator platform is to directly support the rated load and the cab that contains the load. Elevator platforms fall into two categories:

A. Passenger Elevators
B. Freight Elevators

Until the early 1970s, all platforms, whether passenger or freight, used wood flooring supported by a steel frame. The modern elevator platform utilizes an all-steel construction, more efficient and lighter than its wooden predecessor.

4.1 Passenger Platforms:

Typically, within the elevator industry, passenger platforms are generally of three types; combination wood-steel design consisting of a steel frame on top of which is mounted a wooden flooring; the all-steel version which embodies a welded structural frame to which a steel floor plate is welded forming a unitized construction; or the design might be comprised of several sections welded together wherein the stringers and floor plates are modules.

ASME A17.1 Code Section 2.15.5 defines the requirements for the design and construction of platforms. Rule 2.16.1.1 defines the minimum rated load for passenger elevators. In the mid-1970's, a revision to the ASME A17.1 Code allowed an increase in the minimum car inside area by 5% and defined the area as being measured at a point 39" above the platform floor.

The general structural components in a platform assembly are:

A. End channels – which are the front and rear structural members of the platform which support the front of the car, door threshold, toe guards and the stringers.
B. Stringers – are the structural members usually running in a front-to-rear direction of the elevator and are supported by the end channels and near the center by an intermediate support.
C. Floor Plate – the structural plate surface, either monolithic with the stringers, or welded to them. The finished flooring is laid on top of this plate.

In the early 1970's, the ASME A17.1 Code responded to a changing technology and introduced provisions in Rule 2.15.5.4 (previously, Rule 203.5) for *Laminated Platforms* which consisted of steel-faced plywood. ASME A17.1 Code Rule 2.15.5.4 allows the use of Laminated Platforms for passenger elevators having a rated load of 5000 lbs., or less, with the requirements that the deflection at any point of a laminated platform, when uniformly loaded to rated capacity, shall not exceed 1/960 of the span and that the stresses in the steel facing shall not exceed 1/5 of the ultimate strength. Platform frames are not required with laminated platforms.

A typical all-steel welded platform is shown in Figure 6. The passenger platform rests on compressible blocks (usually, rubber; sometimes, elastomeric) located at 6 points as shown. These blocks are supported by a sub-frame called the sound isolation support frame which, in turn, is supported by the car frame plank channels at its approximate center and by the side braces near its four corners.

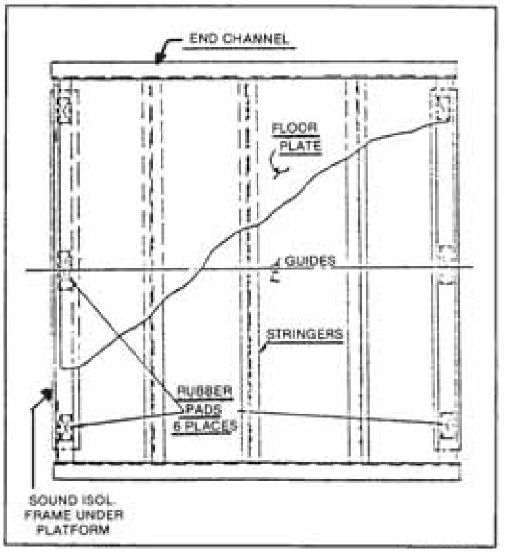


Figure 6

As live load distributes on the platform, deflection of these compressible blocks occurs, thus causing measurable relative displacement between the platform and support frame. As the load increases in the car, the platform compresses the rubber. When a predetermined compression of the rubber blocks is reached, load-weighing switches are activated, and electrical circuits made or broken depending upon whether you want to render the car inoperative or bypass calls, etc. More sophisticated systems were introduced in the 1980s utilizing strain gage technology for load measurement. These latter systems are more accurate and enable more precise load measurement. Sometimes, the load cells are incorporated into the car rope hitch assembly.

Sound isolation and vibration damping, introduced by Otis in 1939, are important features of modern passenger elevators. Through the use of rubber, or other compressible nonmetallic materials, all metal-to-metal contact between the elevator car and its supporting frame is eliminated. The car is permitted literally to "float" on blocks of soft compressible material that cushion car movement, dampen vibration, and prevent the transmission of sound.

4.2 Freight Elevator Platforms:

The construction of freight platforms consists of a welded channel frame with intermediate stringer channels welded to the outer frame. A steel floorplate is then welded to the stringers and frame. For purposes of design analysis, the stringers are supported by at least three points; namely, the front and rear end channels (members) and at the center by the car frame planks. Depending upon the load ranges and the specific manufacturer, there may be additional intermediate supports. The platform end channels are supported by the side braces. A typical freight platform is shown in Figure 7.

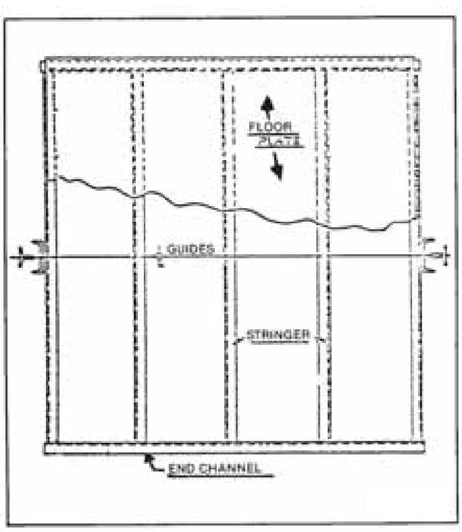


Figure 7

The load-carrying capacity of the floor plate between the stringers depends upon the plate thickness; the capacity of the stringers depends upon its combined strength with that of an effective width of floorplate.

When hoistway conditions preclude the use of a one-piece platform, two-piece or multi-piece sections, bolted together at erection, are commonly furnished.

As noted above, the stringers are supported at a minimum of three points; namely, front, center and rear. Therefore, they are designed as beams continuous over three supports, as shown in Figure 8, and acted upon by a concentrated load at any one point. Since the stringers are spaced at certain intervals, depending upon the strength and rigidity of the floor plate, a certain amount of the rated load can be concentrated at one point. For regular freight loading we consider 1/4 of the rated load acting at one point. For truck loadings, an entire wheel load may occur directly over a stringer.

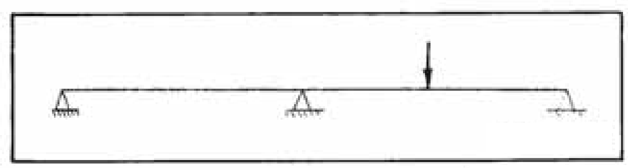


Figure 8

The end channels are treated as simple beams, supported at the ends by the side braces, under the action of a load or loads applied at any point in accordance with the provisions of ASME A17.1 Rule 2.16.2.2 on classes of loading. For regular freight service (Class A loading), as an example, 1/4 of the rated load would be considered as acting at the center of the end channel as shown in Figure 9. This would produce the maximum bending moment.

For Class C – Industrial Truck Loading, the beam would be acted upon by two wheel loads, placed in such a manner so as to produce maximum bending, as shown in Figure 10.

Corner Post Freight Platforms are used when adjacent openings exist. The method of construction is basically the same as for side post except that the frame channel usually borders the periphery of the platform. The design requirements are somewhat different especially for truck loading elevators, since it is possible to have 2 wheel loads acting upon one stringer at the same time. Continued

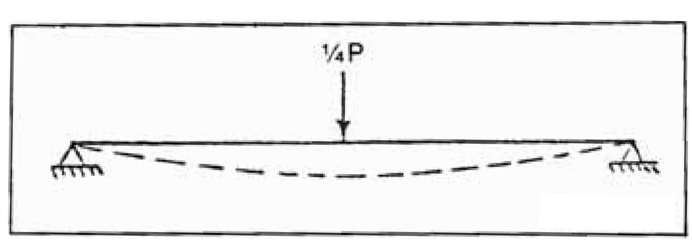


Figure 9

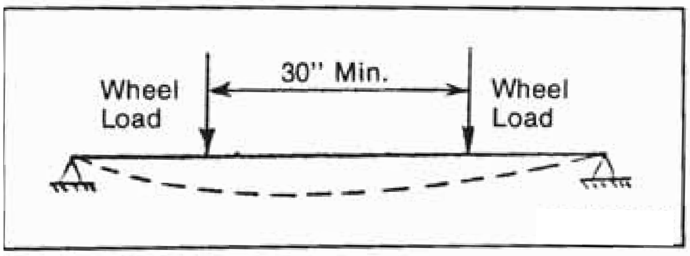


Figure 10

5. BRACING FOR SIDE POST CARS:

The function of the side braces is to support the corners of the platform. One end of the brace is fastened to a bracket mounted on the underside of the platform and the other end to the car frame. Where short side braces are used, as on passenger elevators, the upper end of the braces are fastened to the car frame upright.

The load in the side braces varies with the position of the live load in the car, the dead weights of the platform, enclosure, doors, and with the angle it makes with the vertical. The effect of the side brace load basically takes three forms; namely, it induces a direct axial load along the longitudinal axis of the upright; due to the horizontal component of the brace load, it produces bending and a corresponding deflection of the upright about its strong axis, as seen in Figure 11; it causes the upright to twist.

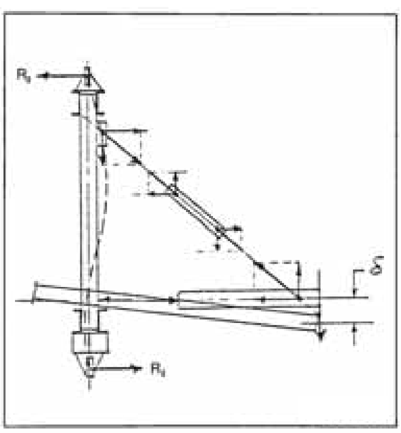


Figure 11

When side braces are designed so that the centerlines of the braces intersect the guide rail at the center of the upper guide shoes, or roller guides, there will be no bending in the uprights caused by the force acting on the braces at this point. This is the main reason that long side braces are used on freight elevators since the brace load in this case is much higher than those associated with passenger loading.

The lower end of each brace is fastened directly to the platform. At this point a bending is caused in the upright for the reason that the thrust from the side brace through the platform is at a point above the guide shoes, which are mounted below the safety plank. But this bending, acting in the strong axis of the uprights and in close proximity to the lower guide shoes, is generally of small magnitude and not serious in most cases.

6. TRUSSES FOR CORNER POST CARS:

The general arrangement for the corner post truss is shown below in Figures 12 and 13:

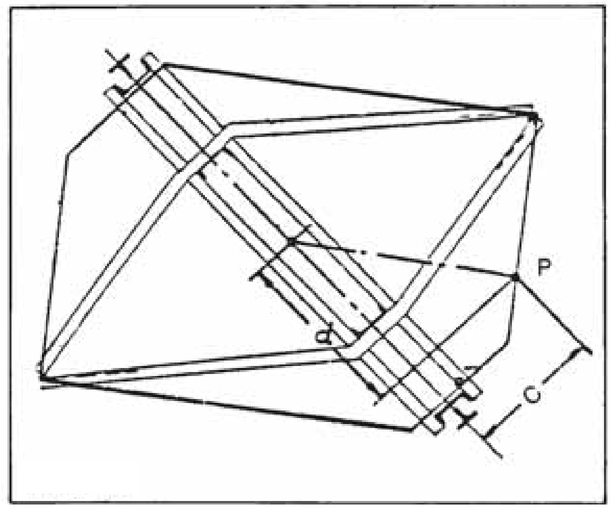


Figure 12

The basic design of the truss embodies two structural members, usually channels bent as required and carrying a tension rod at each end for supporting the outboard corners of the platform. Occasionally when the brace rod loads are very high and the crosshead channels have insufficient stiffness, an additional truss is placed beneath the plank channels and the amount of load carried by each truss depends on the relative stiffness of the crosshead and planks, respectively.

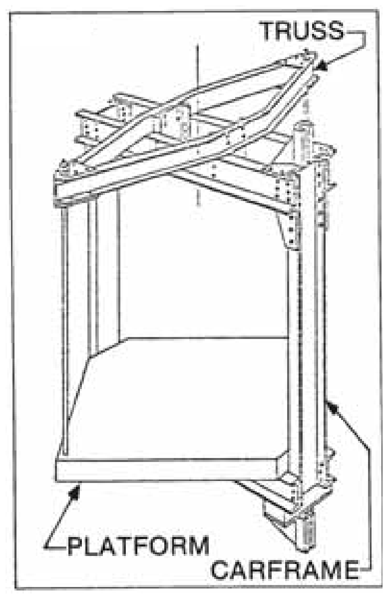


Figure 13

For rectangular shaped platforms, the difference in length of the legs of the truss become so great that one channel will carry practically all of the load, in which case, a different type of truss might be advisable. Since Corner Post conditions vary so widely, no fixed set of rules can be set up; therefore each case must be treated individually. It is important to stress the point again that the use to which the elevator will be put is of extreme importance when designing corner-post structures.

7. CAR FRAMES:

The ASME A17.1 Code has defined the following terms:

Car Frame (Sling): The supporting frame to which the car platform, upper and lower sets of guide shoes, car safety and *the hoisting ropes or hoisting-rope sheaves, or the plunger or cylinder of a direct-acting elevator, are attached.* Specific types include:

Car Frame, Overslung. A car frame to which the hoisting-rope fastenings or hoisting-rope sheaves are attached to the crosshead or top member of the car frame.

Car Frame, Sub-Post. A car frame all of whose members are located below the car platform.

Car Frame, Underslung. A car frame to which the hoisting-rope fastenings or hoisting-rope sheaves are attached at or below the car platform.

7.1 Car Frame Components:

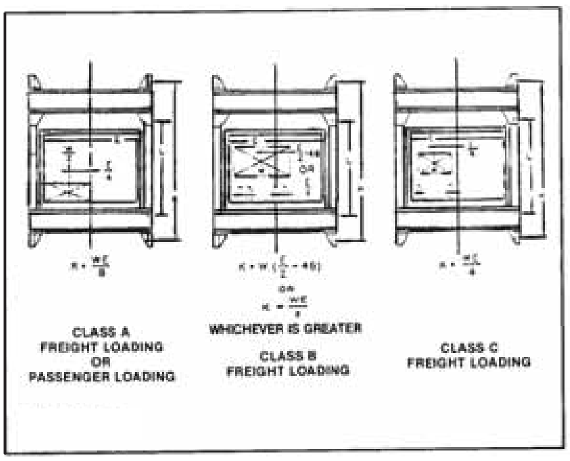


Figure 14

The car frame is a rigid rectangular frame consisting of a crosshead, uprights and plank, as shown in Figure 14.

A. Crosshead usually consists of a pair of structural members, generally channel shaped, which form the top of the car frame.
B. Uprights, also called Stiles, are the vertical structural members at the sides of the car.
C. Plank is the structural member (or pair of members) similar to the crosshead, forming the bottom of the car frame.
D. Guide Shoes are mounted on the 4 corners of the car frame and serve as the point of riding contact between the car frame and guide rails.
E. Car Safety is the device mounted beneath or within the planks, which retards and stops the car in case of an overspeed.
F. Car Frame Hitch is the pick-up point on the crosshead where the hoist ropes are fastened.
G. Bracing Members, although not part of the car frame proper, support the corners of the platform and are, in turn, fastened to the car frame.

Except for very large load capacities, the car frame members have historically been rolled structural steel channel sections as produced by the steel mills; however, in recent years, the elevator industry has seen the introduction of car frame members using formed or bent-up design. The primary advantage of this latter type of design is that you can "put the metal where it does the most good." In this way, more efficient and lightweight structures result.

The general design, necessarily modified to suit the variations in sizes, is substantially the same in all cases where the hoisting ropes are attached to the crosshead; therefore, the following remarks apply to all.

7.2 Car Frame Loading and Effects – Traction Elevators:

The forces acting on the car frame members are more complex than those acting on any other part of the elevator equipment due to the nature of its design and the fact that it must carry variable loads.

If the loading condition, i.e., the manner in which the load enters or leaves the platform, as well as, the position it takes while the elevator is running, is unknown, then the forces acting on the car frame cannot be determined.

If the center of gravity of the rated (duty) load and car coincided with the center of action of the hoist ropes, there would be mainly tension in the uprights and bending in the crosshead and plank, but this condition cannot exist with a moving load; therefore, the car frame must be able to resist turning moments, which produce bending in the uprights and, at times, twisting of the crosshead and plank.

Continued

Since we are dealing with loads that move about while entering or leaving the platform, the exact position of the load at any given time is really unknown, so we must make certain assumptions regarding the positions a load takes while the elevator is being loaded and while it is running. We do know, for instance, the clear opening width at the entrance and that any load passing through this point cannot be more eccentric from the center of the car than the entrance size will permit. On the inside of the car, the load can be no more eccentric than its physical size next to the cab wall will permit. Therefore, we have a starting point for designing the car frame. Figure 14 shows the specified loading eccentricities specified by ASME A17.1 Figure 8.2.2.5.1 as a function of the Classes of Loading, also shown in Figure 15.

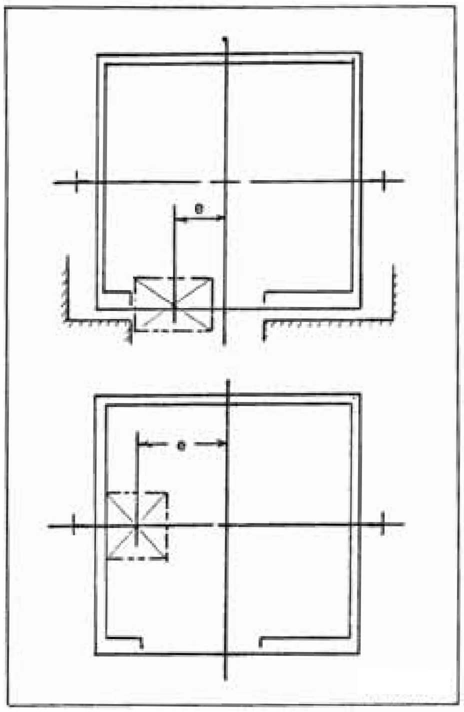


Figure 15

In determining the required sizes of the car frame members, the crosshead and plank seldom present difficulties, as the calculations are in most cases simple. With the uprights, however, the case is somewhat different. Here the sections are more or less limited for the reason that they must occupy a minimum amount of space between the guide rail and the side of the car so as not to encroach too much on the width of the car. The result is that the uprights become limited in strength for bending in the plane of the car frame, and a check is therefore necessary for special cases to make sure they are of sufficient strength and stiffness.

In both cases of loading shown in Figure 15, the car frame is subjected to an overturning moment within its own plane, the magnitude of which is equal to the load times the eccentricity, i.e., to the center of the car frame. The guide shoes contacting the guide rails resist this overturning moment and in doing so, guide shoe forces are impressed upon the shoes and rails. It is these guide shoe forces which produce bending of the uprights. As a result, the uprights deflect and cause the platform to sag on one side. A typical example of this is shown in Figure 16.

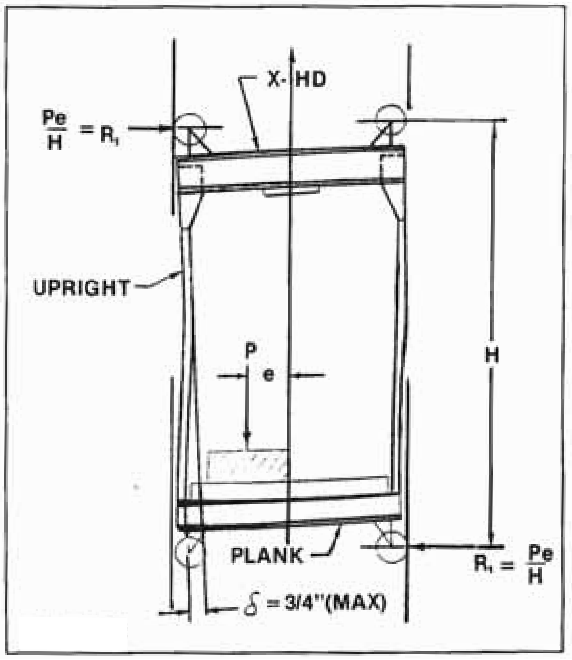


Figure 16

Although side braces and trusses are necessary adjuncts to the car frame, they are usually considered as separate parts of the equipment, since either type of platform supports may, under certain conditions, be used with the same type of car frame. When taken in connection with the forces acting on the car frame, a distinction must be made, since the stresses induced by the trusses are not the same as those caused by the side braces. As a general rule, Trusses cause greater stresses on the car frame than side braces and will be treated in a subsequent section.

The following is a brief outline of the points that must be considered in order to determine the required strength of uprights for the most common cases, during loading and running conditions.

It was noted previously that space beyond the car line was at a premium because it represents lost rentable floor space in the building per floor, and so, for that reason, the car frame uprights have been turned in such a position so that they occupy a minimum amount of space adjacent to the car. However, in so doing, we have had to sacrifice a lot of strength in the upright. In this position, the upright will bend about its weak axis. Occasionally, when the rated loads are high, causing large car frame bending moments, and the available hoistway space small, alternate means of structural reinforcing must be used, such as, adding reinforcing members. When the loads become too great for these types of construction, typically occurring on heavy duty freight cars, double uprights are placed in such a manner so that they will bend about their strong axis; however, hoistway space is generally sufficient on these jobs.

A simple case of a side post elevator subject to uniformly distributed loads and arranged with 4 side braces will be discussed. This loading is seen in Figure 16 in elevation and also in the plan view in Figure 17.

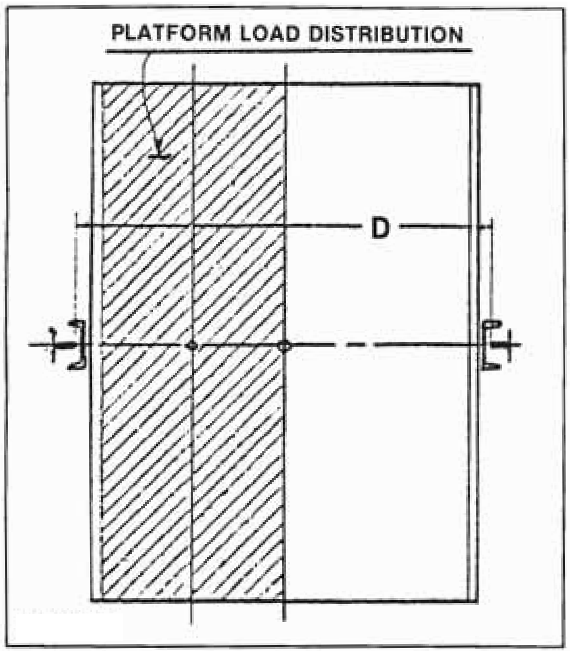


Figure 17

This is the simplest case and the only one where the loading condition is definitely known. The maximum bending moment in the upright occurs when one-half of the rated (duty) load is uniformly distributed over one-half of the platform area between the side of the cab and the centerline. The overturning moment, M, is equal to the load, P/2, times the distance, E/4, and is equal to PE/8.

Expressed mathematically,

$$M = \left(\frac{P}{2}\right)\left(\frac{E}{4}\right) = \frac{PE}{8}$$

This overturning moment, M, causes reactions at the guide shoes which, in turn, produce bending about the weak direction of the upright and bending of the guide rails. In addition, the uprights are also in tension due to the weight of the rated load, car and compensation, if provided. The ends of the platform are supported by the side braces which are, in turn, fastened to the upright.

When short side braces are used, as shown in Figure 11, which is the standard arrangement for passenger elevators, an additional bending moment is produced in the upright due to the brace loads, however, these moments cause bending about the strong axis of the upright and are of very low magnitude. When long side braces are used, as shown in Figure 18, this additional bending does not occur.

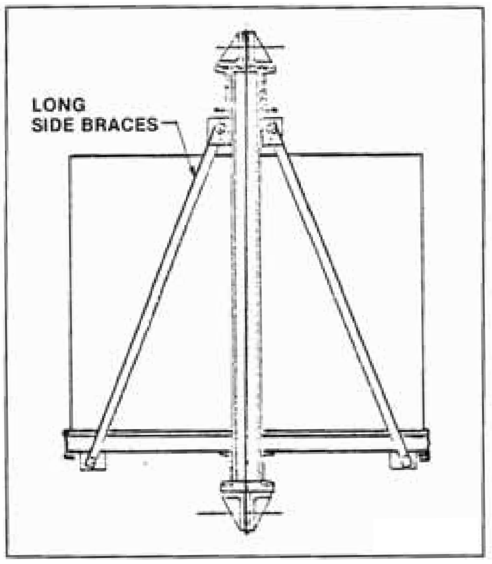


Figure 18

Corner Post Cars are used where it is necessary to have adjacent openings. In this case, the car frame is located approximately on the diagonal of the platform. The loads imposed on a corner post car frame are generally more severe than on a side post car. See Figures 19 and 20.

Continued

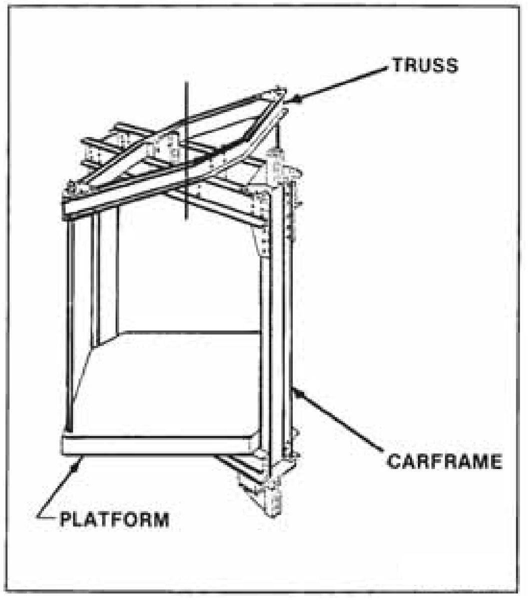


Figure 19

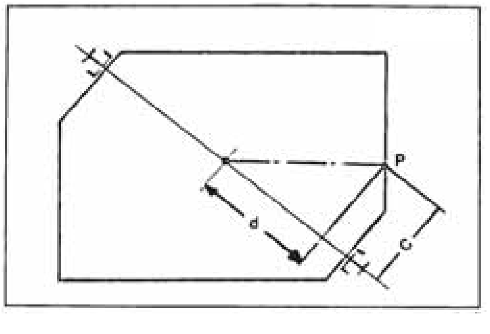


Figure 20

In this case, more than in any of the previous cases, the exact loading condition must be known, if an economical design of car frame is to be provided. The points of application of the load with reference to the entrances both at loading or unloading, as well as, its position with reference to the center of the car while the elevator is running, has such a great influence on the size of the required car frame members, that unless the loading is known, the extreme conditions must be assumed for our calculations, resulting in a much heavier construction than may actually be required.

Two bending moments are set up for corner post cars; namely, Pc and Pd, each of which produces bending of the upright in two planes 90° apart. The moment, Pc, acts through the truss rod which, in turn, is transmitted to the truss. The truss then tends to twist the crosshead which, in turn, induces a moment at the upper end of the upright. This, in turn, is reacted by the guide shoes in contact with the rails. This twisting moment is divided between the two uprights in proportion to its distance from each; i.e., it is equally divided between the uprights for a square car, but for a rectangular car one of the uprights will take a greater part of the bending moment.

It will be understood from Figure 20 that, if the platform has considerably more length than width, or vice versa, and if the load enters at the short side, the turning moment, Pd, which acts in the weak direction of the uprights, may become quite large, depending on how close to the uprights the center of gravity of the load will set.

The total sag of the corner of the platform is caused by the cumulative effects of:

1. Crosshead deflecting vertically due to the direct load on truss.
2. Crosshead will twist carrying the truss with it and due to the twist; the deflection at the end of the rod is magnified.
3. The truss itself will deflect.
4. The uprights will deflect due to the twist of the Crosshead.
5. The Guide Rails will deflect.
6. Stretch of the hoist ropes.

In the loading cases described above, it should be noted that stresses are induced not only because of the live load, but also due to the dead load of the car itself. The objectionable deflections of the platform are those due to the live load only. Deflections due to dead load, such as, the weight of the platform, enclosure, truss, etc., can be taken up by adjustment of the truss rods, provided the allowable stresses in the members are not exceeded.

The few cases mentioned above are those most frequently encountered and constitute the greater part of the problems in car frame members insofar as the loading conditions are concerned. In addition to designing the car frame for normal running and loading conditions, emergency conditions, such as, those caused by Safety Application and Buffer Engagement, are also investigated.

During a Safety Application, the car frame must withstand the forces impressed upon it when the safeties grip the rails. Since the safeties are manufactured items with manufacturing tolerances on them, and also since no two guide rails will be lubricated the same, a difference in retarding force at the two sides of the car will exist. This difference in forces has the same effect as an eccentric load, and therefore, an overturning moment will be induced. As noted before, this overturning moment produces bending of the uprights. In addition to the bending, the uprights will also be subjected to compression due to the part of force of retarding which is transmitted through the side braces.

At Buffer Engagement, the plank channels are subjected to a severe bending load. The uprights will undergo compression and bending depending on the position of the load in the car.

For these emergency conditions or for those times when tests must be conducted, a much higher allowable stress is used as is allowed by ASME A17.1 Rule 2.15.10. This is justified since the time duration over which these high forces act, is very small plus the fact that such occurrences are emergency ones.

In the cases previously discussed, it has been assumed that the car frames were suspended by ropes attached to the center of the crosshead which is the case of 1:1 roping (Figure 21), 2:1 roping with one sheave (Figure 22), and 2:1 hitch when two sheaves are used, provided all of the ropes lead around the two sheaves (Figure 23).

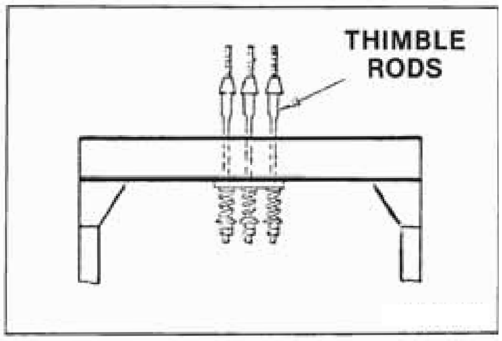


Figure 21

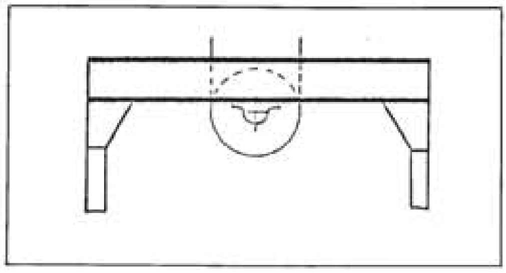


Figure 22

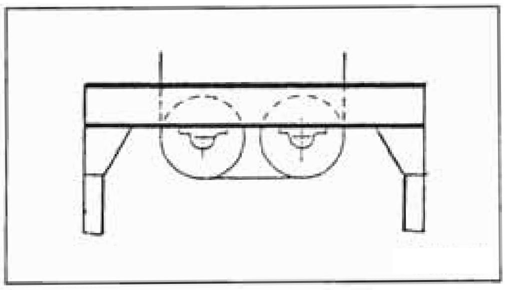


Figure 23

On occasion, when there is insufficient overhead room in the hoistway, requiring a low-height car frame, the 2:1 sheaves are mounted under the car. Depending on layout conditions, the sheaves may be arranged with a pick-up mounted parallel to the planks or with a diagonal underslung pick-up. These cases are shown in Figure 24.

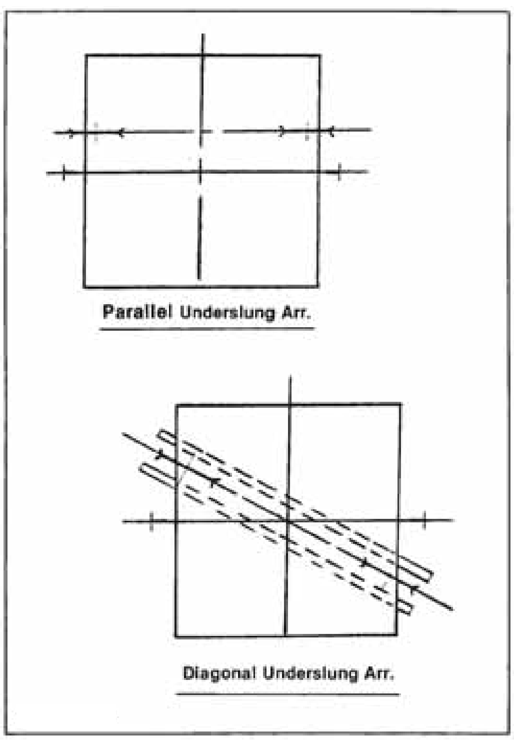


Figure 24

The permissible fiber stresses in the car frame and hitch members are specified in ASME A17.1 Code Rule 2.15.10 or other building codes, as applicable. The allowable deflections are covered in Rule 2.15.11. The ASME A17.1 Code, however, does not fix the amount that the platform edge may sink below the landing sill at the time the load is applied. This amount depends to some degree on the stiffness of the car frame, platform and rails, as well as, the elasticity of the hoist ropes. Absolute rigidity can, of course, never be obtained; therefore, the amount which can be allowed is controlled by the purpose for which the elevator is used.

7.3 Car Frame Loading and Effects – Hydraulic Elevators:

Car frames for hydraulic elevators are constructed basically the same as those for traction elevators, except that since the lifting is accomplished by a plunger fastened to the underside of the planks, the planks will usually be larger than the crosshead and safeties are not generally furnished. The typical arrangement is shown in Figure 25.

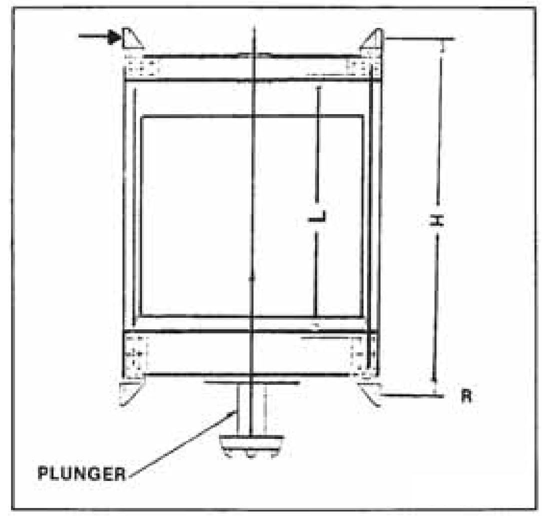


Figure 25

The uprights (stiles) will be subjected to the same bending moments that were described for traction elevators, but in addition, they will have a compressive load in them due to the platform loads coming up through the side braces. Since this compressive load is quite appreciable, the slenderness ratio of the upright must be kept low enough to ensure that the member will not buckle. When long side braces are used, the L/r (slenderness ratio) is limited to 120 by the ASME A17.1 Code; however, when short side braces are used for passenger application, an L/r of 160 is allowed since the compressive load from the braces acts over a shorter length of upright. L is the vertical distance from the lowest bolt hole in the crosshead to the uppermost bolt hole in the plank-to-upright connection, as seen in Figure 25.

8. GUIDE SHOES:

Elevator and counterweight guide shoes are either the sliding or roller type. Before the advent of the roller type, the swivel type sliding shoe was used almost exclusively for passenger service elevators. In this type, the shoe is held in a bracket and arranged to turn so that it may adjust itself to bear evenly on the sides of the guide rail. In the direction against the face of the rail, the shoe is backed by a spring, held in the bracket, and adjustment is provided to obtain the desired clearance, or float, in this direction.

For freight elevators, the guide shoes are generally of the sliding type without provisions for swiveling or align-

Continued

ing themselves automatically to the sides of the rails, therefore, any misalignment due to inequalities of the car frame members must be corrected by means of shims. The shoes are usually provided with removable cast iron gibs, usually in one piece. Because of the sliding friction, most shoes of this type embody guide shoe lubricators. In some applications, guide shoe gibs using nonmetallic material, such as, Nylatron, has been used successfully.

The roller guide, now supplants the swivel type shoe on most passenger elevators. This guide allows the elevator car to ride smoothly even though the guide rails are not smooth and straight. The float is limited by the closeness of the safety jaws to each side of the rails. Each roller is generally mounted to a spring-loaded lever which pivots about the roller guide stand.

Some of the principle advantages of the roller guides are:

A. The oil and grease are eliminated from the hoistway, which cuts down the amount of maintenance, particularly in cleaning hoistway walls and pits, and also eliminating a serious fire hazard.
B. All of the rail's knocks and scraping noises are eliminated.
C. Riding quality is improved, especially on high-speed elevators.
D. Current consumption of the elevator driving machine motor is considerably decreased.

Each roller guide assembly consists of 3 rubber tired wheels, as a minimum, generally resiliently mounted through springs or other means. The elevator, therefore, is riding on 12 wheels in contact with the guide rails. It is important that the cars be reasonably well balanced when setting a job up in the design stage so that guide shoe pressures due to dead load be as close to zero as possible. Over the last couple of decades, roller guide assemblies incorporating 6 rollers per shoe have been used very successfully. In this case, the elevator is guided by 24 rollers, which improves the car riding quality.

9. GUIDE RAILS:

The functions of the guide rail are as follows:

A. To guide the car in its vertical travel and to prevent horizontal movement or lurching of the car as much as possible.
B. To prevent tilting of the car due to eccentric load, such as, when a group of passengers stand on one side or at the rear of the car.
C. To enable stopping and holding the car at safety application.

9.1 Guide Rail Loading:

A17.1 Code Section 2.23 specifies the shape of the guide rails, the material, strength and load rating information; however, it has long been recognized by the elevator industry, users and consultants that Section 2.23 needs extensive review and revision to reflect contemporary structural design.

In trying to formulate a reasonable approach to revising Section 2.23, two principal design directions emerge, each of which are briefly explored below. The short-range approach to a revision would involve developing a rational column formula that will fit the existing rail curves as closely as possible and which can be used to extrapolate values not presently covered. Additional factors, or modification factors, could be developed to include the effects of large rail spans wherein two rail joints occur. The long range approach should be a structural performance specification which would prescribe or otherwise define strength and rigidity requirements to suit static (non-moving) forces imposed on the rails as an overall structural system to the moving car and counterweight at normal running conditions, as well as, emergency stopping conditions.

With an eccentric load in the car, it is prevented from tilting by the guide shoes or rollers pressing on the rails. The rail now acts as a beam supported by the brackets and it must have sufficient strength to carry these forces and also sufficient stiffness to keep the front edge of the platform level with the landing as loads enter or leave the car. The properties of the rail now involved are the section modulus and moments of inertia about both axes. In the case of passenger elevators, where the eccentric loads are small, these properties are not as important as with freight elevators where eccentric loads are usually very large.

The guide rail acts as a column at safety application and the greater the load it must support, the larger is the required cross-sectional area of the guide rail. The weight per foot of the guide rail, of course, is directly proportional to the cross-sectional area. In addition to cross-sectional area, a column must be supported at certain intervals or it tends to buckle if the points of support are too far apart. The distance between the points of support to prevent buckling depends on the minimum moment of inertia and on the cross-sectional area of the guide rail.

In addition, a safety application on such a pair of rails would tend to spread the rails and thereby cause one of the safeties to pull away from the rail. As stated previously, the most important factor affecting the design of the guide rail and its supports is the Class of Loading.

Guide rail shapes other than the conventional Tee shape are permitted as long as they meet the requirements specified by ASME A17.1 Rule 2.23.3. Other shapes which have been deployed include the circular hollow tube rails and the Omega-shaped rails. Since circular sections have uniform properties, they are ideally suited as columns since the moment of inertia is constant about any principal axes. The round rail has been used on hydraulic elevators and counterweights where a safety would not be applied.

Guide rail loadings are shown below in Figures 26 and 27.

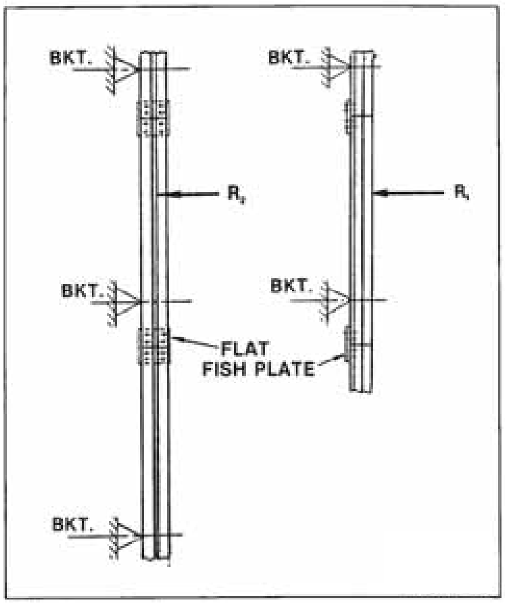


Figure 26

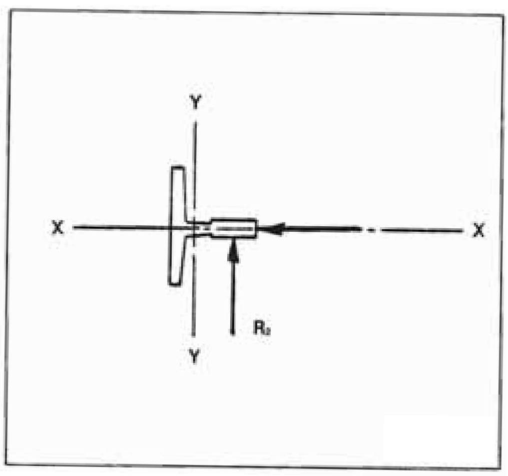


Figure 27

From Figure 26, it is noted that R_1 is the post-wise rail force which acts in the plane of the car frame; R_2 is the front-to-back rail force which acts normal to the plane of the car frame. The effects of these forces on the rail are as follows:

a. R_1 causes the guide rail to bend in one direction.
b. R_2 produces both bending and torsion (twisting) of the guide rail.

9.2 Guide Rail Supports:

Where the guide rail forces are not very large as in the case with passenger elevators, the typical fastening of the rail to its brackets is shown in Figure 28.

If supports cannot be provided at sufficiently close intervals or, if these supports become so numerous as to be impractical, the section of the rail must be reinforced between brackets. This is accomplished in various ways by

Continued

means of channels or other structural sections fastened to the back of the rail as shown typically by Figure 29 and subject to ASME A17.1 Code Rule 2.23.4.1(b).

While the strength and stiffness of the rail, with or without backing, is important, of equal importance is the strength and stiffness of the structure to which the guide rails are fastened, which may be brick walls, concrete walls, steel framing, etc., depending on the building construction.

It also frequently happens that the hoistway framing, where supports can be provided, is a considerable distance from the desired location of the rail, in which case it may be necessary to provide columns of sufficient strength to resist bending, as well as, torsion due to the force on the side of the rail, which tends to twist the column with the torsional (twisting) moment.

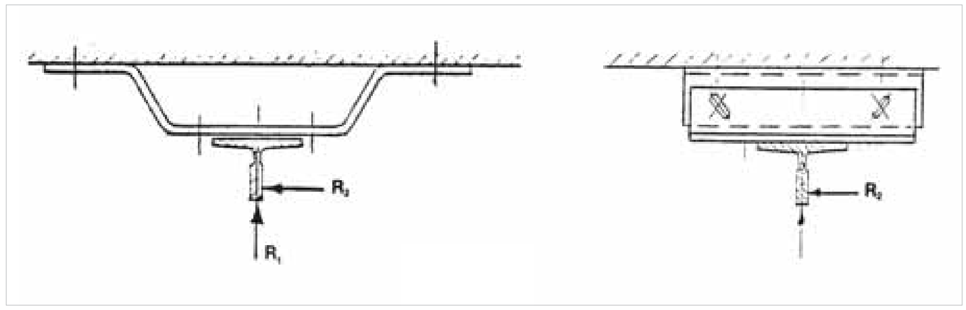


Figure 28

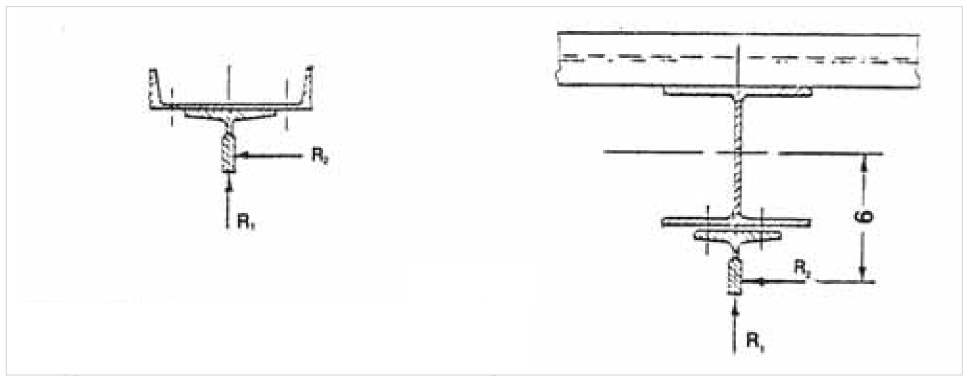
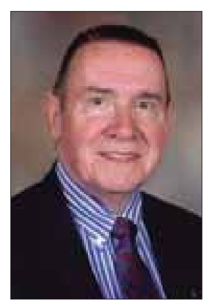


Figure 29

Learning-Reinforcement Questions

Use the below learning-reinforcement questions to study for the Continuing Education Assessment Exam available online at www.elevatorbooks.com or on page 159 of this issue.

- Why is it important that the elevator designer know the usage that the building owner or manager intends for the elevator during its life cycle?
- Why is it important to have a basic understanding of the forces acting on the elevator structures and the effects of these?
- What effect might a weak car frame upright have on the level condition of the platform when the car is at a landing with the doors open?
- Why is it important to understand the necessity of having strong car frame joints?
- Why is the measurement of the inside car area of a passenger elevator important?
- Why is it important to understand the effects of corner-post elevator loading?
- What would happen if the car frame upright (stile) deflected too much while the car was in flight?
- What would happen if the guide rail on one side of a car deflected too much, causing the guide shoe on the opposite side of the car to disengage its guide rail?
- What kinds of forces are imparted to the guide rails when the car safeties set?
- What are the primary functions of the guide rails of a passenger traction elevator? How about for a freight elevator?



George W. Gibson has 50 years of experience in the technical and managerial aspects of the elevator industry. In a career spanning 37 years with Otis, Gibson has held several design engineering, engineering management and corporate management positions. He is currently president of George W. Gibson & Associates, Inc., an elevator consulting firm specializing in elevator technology, strategic technical planning, codes and standards, product safety, and technical support of litigation. Gibson is a member of the QEI Standards Committee, American Society of Mechanical Engineers (ASME), ASME Board of Directors on Codes and Standards, ASME A17 Elevator Safety Code Standards Committee, and chairman of the A17 Mechanical Design Committee, A17 International Standards Committee, A17 Earthquake Safety Committee, A17 Ad Hoc Committee on Door Protection and A17 Ad Hoc Committee on Elevator Stopping. In his role as chairman of the ASME A17 International Standards Committee, he has been the head of the U.S. delegation to the International Standards Organization Technical Committee 178 on Elevators and Escalators since 1981. In 1997, he was the recipient of the ASME "Codes and Standards Medal," became a fellow of the ASME in 2007 and received the ASME Dedicated Service Award in 2007. Gibson is the chairman of the advisory board of NAESA International (NAESAI), advisor to the NAESAI Board of Certification, past regent of the Elevator Escalator Safety Foundation and a member of the board of executives of the International Association of Elevator Engineers. He is also a member of the board of directors of Elevator World, Inc. Gibson is a civil engineer and has taken extensive postgraduate studies in advanced theories of structures, mechanics and mathematics.

ELEVATOR WORLD Continuing Education Assessment Examination Questions

Instructions:

- Read the article **"ELEVATOR HOISTWAY EQUIPMENT: Mechanical and Structural Design, Part 1"** (page 97) and study the learning-reinforcement questions.
- To receive **two hours** of continuing-education credit, answer the assessment examination questions found below online at www.elevatorbooks.com or fill out the ELEVATOR WORLD Continuing Education Reporting Form found overleaf and submit by mail with payment.
- Approved for Continuing Education by **NAEC for CET and CAT and NAESAI for QEI**.

1. The basic function of any structure, such as beams, frames or columns, is to:
   a. Be simple.
   b. Support the loads imposed on it.
   c. Withstand the environment.
   d. Be welded at the appropriate points.

2. A basic law applicable to structures is known as Newton's Third Law, which states:
   a. "For every beam, there is a weight."
   b. "Objects at rest remain at rest unless acted upon by an external force."
   c. "For every action, there is a reaction."
   d. "For every traction elevator, there is a counterweight."

3. All structural materials, such as beams and columns, have an ultimate strength, which is:
   a. The point at which paint starts peeling from the structural member.
   b. The point at which the structural member will fail.
   c. The point at which the applied loads will cause the structural member to start bending.
   d. The point at which the deflection of the structural member becomes noticeable.

4. The two most important characteristics of any structure are:
   a. Its buckling strength and vibration damping capability.
   b. Its size and weight.
   c. Its strength and rigidity.
   d. Its weldability and color.

5. While a long structural beam might be strong enough to support the loads imposed on it, the beam might:
   a. Be too flexible and act like a spring.
   b. Be too stiff and vibrate.
   c. Deflect too much, causing it to fail.
   d. Act like none of the above.

6. One method of ensuring rigidity at the joints where the ends of a car frame crosshead is fastened to the uprights (stiles) is to:
   a. Fasten the crosshead to the upright flanges with not less than 8 rivets.
   b. Retain the nuts on the connecting bolts by drilling holes through the bolts and inserting cotter pins.
   c. Fasten the crosshead to the upright flanges with not less than 6 body-fit bolts.
   d. Use gusset plates, fastened by bolts, rivets, or welds, to connect the crosshead to the uprights.

7. Elevator usage is specified in the *ASME A17.1 Safety Code for Elevators and Escalators* by Classes of Service. All of these classes are contained in one of the following statements:
   a. Passenger and Construction Lifts.
   b. Automobile Truck Service and Industrial Truck Service.
   c. Passenger, Regular Freight, Automobile Truck Service and Industrial Truck Service.
   d. Shipboard Service and Industrial Truck Service.

8. One of the most severe loading conditions on a freight elevator is caused by:
   a. Stacks of paper on a hand dolly.
   b. Fork-lift (industrial truck) service.
   c. Tractor trailer loading.
   d. Passenger overload.

9. The inside area of a passenger elevator is required by the *ASME A17.1 Safety Code for Elevators and Escalators* to be measured across the cab walls at a height above the platform at:
   a. 1220 mm (48 inches).
   b. 460 mm (18 inches).
   c. 1000 mm (39 inches).
   d. Any height.

10. Corner-post platforms are used when:
    a. Front and rear openings are provided at opposite ends of the elevator.
    b. Adjacent openings exist, such as front and side, or side and rear.
    c. Multiple openings are provided on the same side of the elevator.
    d. All of the above.

11. On a conventional side-post elevator, the function of the side braces is to:
    a. Support the 4 corners of the platform.
    b. Support only the 2 corners of the platform located furthest from the car frame planks.
    c. Support only the 2 corners of the platform located closest to the car frame planks.
    d. Relieve the loads supported by the hoist ropes.

12. On corner-post traction elevators, a truss is furnished on top of the crosshead to support:
    a. The weight of the car top.
    b. The car frame crosshead.
    c. The 2 outboard corners of the platform.
    d. The 2 corners of the platform resting on the planks.

13. The off-center placement of loads on a side-post elevator platform toward the side of the car toward the guide rails can cause:
a. The car balance to be changed.
b. The car frame uprights to deflect, causing the platform to sag on one side.
c. The side braces to stretch.
d. None of the above.

14. What effect does the off-center placement of loads on a side-post elevator platform toward the side of the car toward the guide rails have with respect to the guide rails themselves?
a. The overturning of the car is resisted by the guide shoes in contact with the guide rails at the diagonally opposite corners of the car frame, causing the affected guide rails to bend.
b. The overturning of the car is resisted by the weight of the platform and car frame.
c. The overturning of the car is prevented by the car frame uprights (stiles).
d. No effect.

15. Guide rails used for a traction passenger elevator have important functions. Which of the following does not apply?
a. To guide the car in its vertical travel and to prevent horizontal movement or lurching of the car as much as possible.
b. To maintain the vertical leveling accuracy at landings.
c. To prevent tilting of the car due to eccentric load, such as when a group of passengers stand on one side or at the rear of the car.
d. To enable the stopping and holding function for the car at safety application.

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