

COMMERCIAL VEHICLE FRAME DESIGN:

Introduction:

Frame is a ladder shaped structure with two longitudinal rails/beams (Frame side members) and properly located many integrating and reinforcing cross members, which form the ladder structure that is used as the interface/platform between the power package and the body package in Automobiles. This structure should ensure certain needs and requirements (functions) for the functioning of the automobile.

The two primary load-carrying members are called side-members and are joined together at proportionate points by cross-members. The side members and cross members form an integral structure for the support of all chassis equipment and payload. Although the simplest frames have straight side-members in the plan and elevation views, packaging requirements for modern, high-powered, V-type engines frequently require more complex shapes at the engine area.

This structure should possess both flexibility and rigidity for the successful functioning of the vehicles in various applications and operating conditions.

Functions of Frame:

Packaging – interface/platform for power package and Body package.
– Provisions for mounting all the aggregates (support, attachment, location, and alignment).

Load bearing – to carry the payload (principal function), Static and Dynamic loads (braking, cornering, tipping and articulation) of the Mountings (aggregates, Load bodies...etc). The structure should withstand all the loads with minimum structural material. (more strength to weight ratio structures/sections)

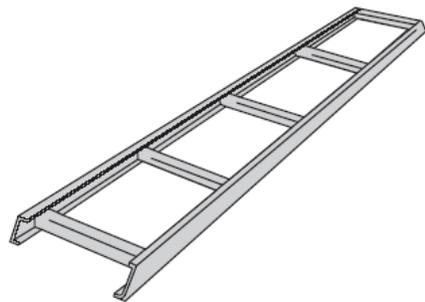
The Loads are:

Vertical bending

Lateral Bending

Torsion

Horizontal Lozenging



Frame design therefore relates to the arrangement and proportioning of components that will produce an efficient, economical, and functional structure.

The design should also ensure the following:

- Ergonomical design
- Provision to manufacture with existing tooling, easy manufacturability.
- Life of the vehicle, lesser maintenance.
- Cost consideration, and weight consideration.
- Using rationalized aggregates.
- Adherence to CMVR rule for dimensions and locations.

PACKAGING:

The spatial relationship of the frame to the vehicle is largely determined by location requirements of chassis and payload equipment. These requirements are set by industry standards and governmental regulations. For example, the frame length results from various vehicle codes which describe:

1. Overall length restriction for tractor-trailer combination,
2. Maximum length of any single unit in the combination
3. Overall combination wheelbase and axle spacing
4. Permissible axle loadings

Also considered is the turn clearance between the rear of the cab and the front of the trailer. A summation of all these factors determines the minimum practical limits for wheelbases.

Industry standards for frame width and height, as proposed by an SAE recommended practice (Report J691) is set at 34”(863.4mm). The width standard results from a need to accommodate four tires, two brakes, and suspension components within the overall vehicle width limitation of 96”(2438.4mm).

SAE Report J696 proposes a 48”(1219.2mm) top of 5th wheel to ground height with a 10X20 tire. As most 5th wheels are 7-9” high, the top of the frame to ground dimension becomes approx. 40”(1016mm).

Components generally mounted on the Frame:

- Bumper & mounting
- Steering box mounting
- Spring bracket mounting
- Battery carrier
- Air tank mounting
- Fuel tank mounting
- Engine mounting
- Gearbox mounting
- Transfer case mounting
- Spare wheel carrier mounting
- Cross member mounting & spacing
- Sub frame mounting & U bolt locations
- Fifth wheel coupling mounting
- Cab mounting
- Propeller shaft centre bearing mounting
- Silencer mounting
- Air cleaner mounting.
- Pay Load Mountings

LOAD BEARING:

The truck frame is designed for both strength and deflection. To ensure that the vehicle is adequate for the intended operation and that the installation does not adversely affect chassis durability, some understanding of the terms related to frame design is required.

BASIC TERMINOLOGY:

TERMS RELATED TO STRENGTH-

1. SECTION MODULUS:

A function of section dimensions. This term is meaningless when used by itself to indicate frame strength since cross sections of cardboard and steel having identical dimensions will have the same section modulus. The material must also be specified to determine side-rail capability.

2. RESISTING BENDING MOMENT:

This is the product of section modulus and material yield strength. This term provides a measure of frame side rail capacity and a means of comparing side rails of different dimensions and materials.

TERMS RELATED TO DEFLECTION-

1. MOMENT OF INERTIA

This is a function of section dimensions, and with a physical property of the material known as Young's Modulus, is used to determine bending deflections. High tensile and low carbon steel side-rails of the same cross-section under the same load will deflect at the same rate provided, the yield point of the material is not exceeded. A heat treated side-rail would be capable of sustaining roughly three times the load of a low carbon rail at three times the deflection before yielding.

2. TORSION RESISTANCE FACTOR

This is a measure of the stiffness of a frame or chassis in twist. This term is easier to determine by measurement than by calculation.

TERMS RELATED TO APPLIED LOAD-

1. BENDING MOMENT

Summation of all moments acting on the beam (side-rail) at a given point

2. DESIGN FACTOR

This is equal to the frame side-rail capability,(Resisting Bending Moment) divided by Applied Bending moment. An on-highway vehicle with a design factor of 2.5 would not be suitable for an off-highway application with a design factor indicated at 4 or 5.

OPERATING CONDITIONS:

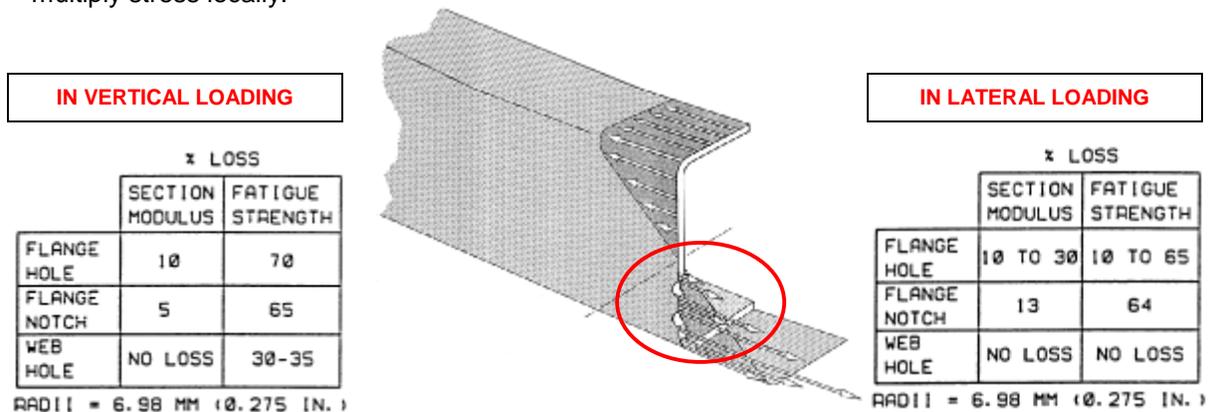
Knowledge of the customer's requirements and operating conditions is vital to successful installations. Most installations, even the most crude, would suffice if the vehicle were static most of its life. This is hardly the case. Vehicles accumulate from perhaps a minimum of 50,000 miles to millions in case of highway tractors.

TYPE OF TERRAIN

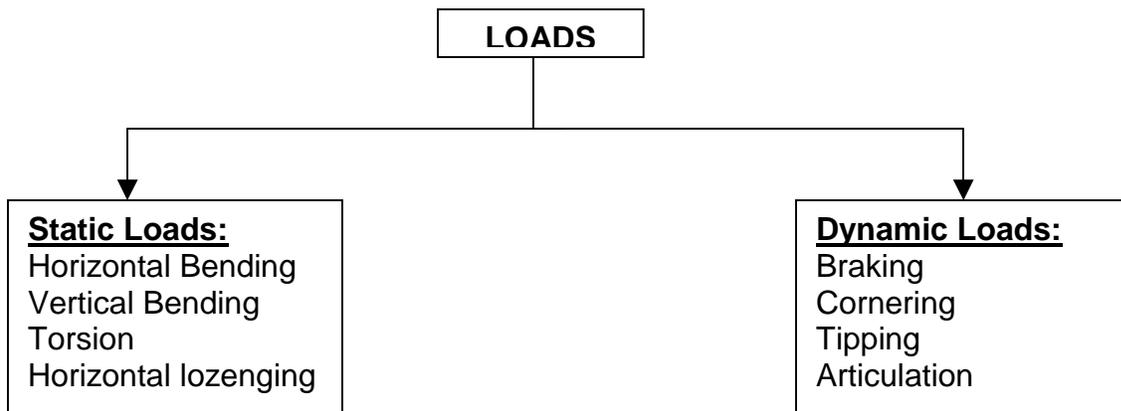
The vehicle may operate the major portion of time off-highway, on-highway, or a combination of both. Rigidity of any installation now becomes a consideration. Trucks frames are relatively flexible in twist to enable the vehicle to travel rough terrain with stiff suspensions, without the wheel losing ground contact or causing high local stresses in the frames. The installation of a compact rigid piece of equipment (such as a winch) can adversely affect durability by locally restricting frame deflections and causing high stress concentration.

LOAD FACTOR

Steel structures may be stressed to just below yield under static conditions without failure. When the loading fluctuates, the maximum permissible stress is reduced. The load required to cause eventual failure decreases on the total number of applications of cycles increase. Bolt holes, brackets, welds, and changes in cross section all act as stress-concentration and serve to multiply stress locally.

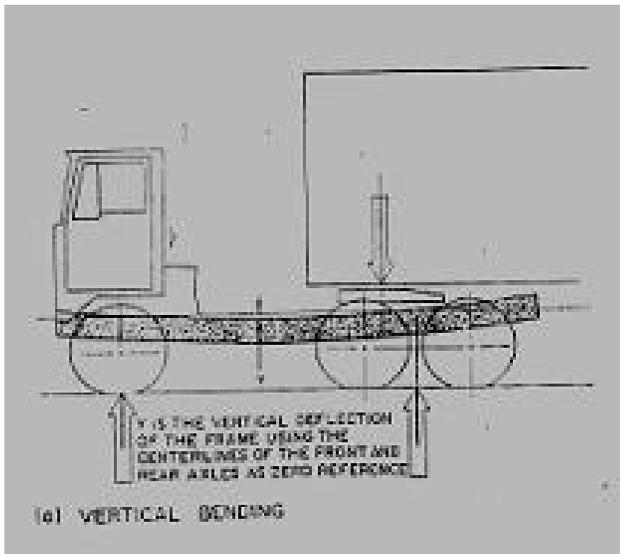


TYPES OF LOADS:

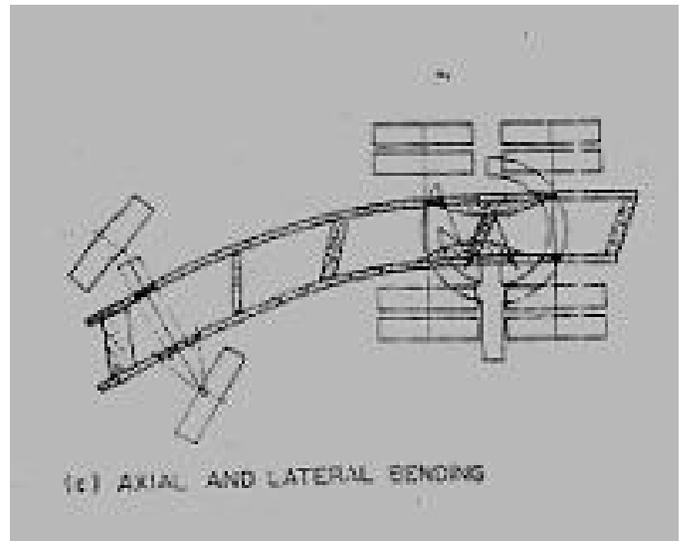


Static Loads:

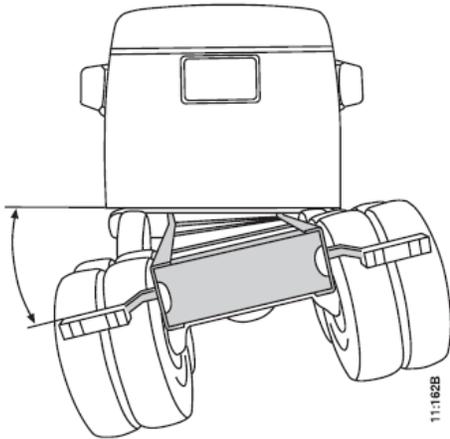
1. Vertical Bending:



2. Horizontal Bending

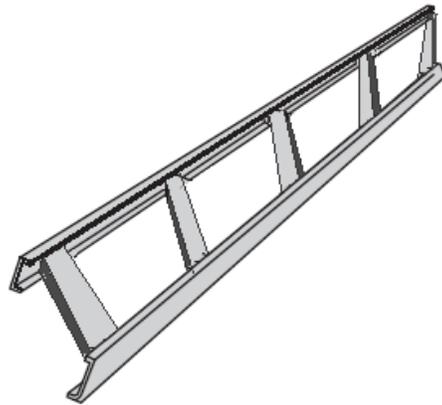


3. Torsion



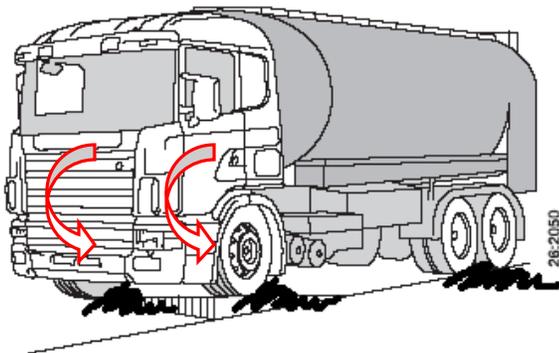
Twisting of the chassis frame.

4. Horizontal Lozenge/ Parallelogram effect

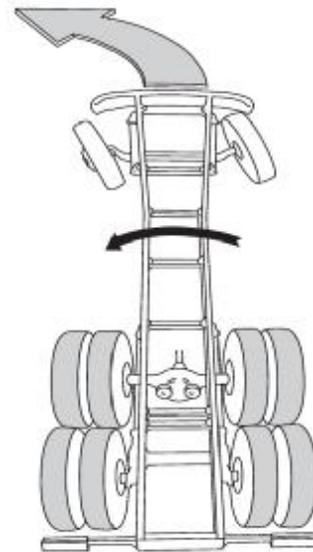


Dynamic Loads:

1. Braking

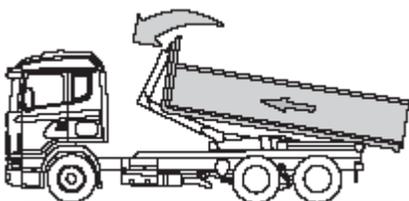


2. Cornering



Lateral forces during cornering.

3. Tipping



4. Articulation



Static forces:

Static forces are caused by the mass (dead weight) of the truck and its payload. When stationary, the truck is only subjected to static forces. The stresses caused by these static forces can be calculated for different truck and body types.

An auxiliary frame is required to distribute the load evenly across the chassis whenever the chassis frame carries a point load such as that applied by the fifth wheel. With low payloads and good driving conditions, the auxiliary frame can be replaced with angle brackets for the fifth wheel mounting plate.

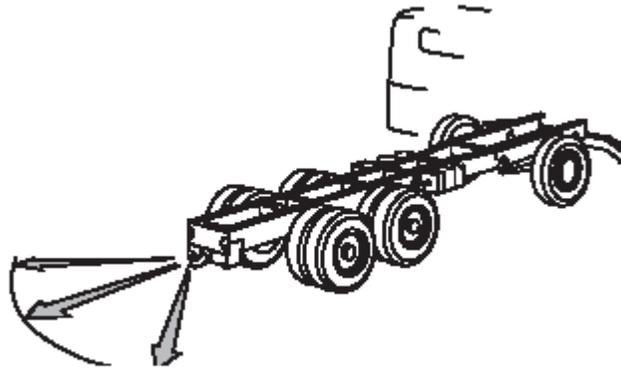
Dynamic forces:

Dynamic forces arise while driving and are largely due to shocks from the road surface. The magnitude of these forces and their effect depends on factors such as road speed, the nature of the road surface and, to a very large extent, on the chassis selected and on the design of the body. A minor change in one of these factors can completely change the effect. When there are dynamic forces, resistance to fatigue is extremely important. Therefore, the calculation and estimation of dynamic forces depends on the conditions in each individual case. The magnitude of dynamic forces is dependent on factors such as road speed and the nature of the road surface.

Lateral forces (dynamic):

The chassis frame may be subjected to large lateral forces. This applies particularly to trucks with a long wheelbase, bogie trucks and trucks with a long rear overhang used for towing a trailer. A truck with an extremely long wheelbase must have particularly high lateral rigidity. If rigidity is insufficient, the truck will "snake" while traveling. In addition to wheelbase, rigidity in the chassis frame also depends on the body. Cross members that prevent lateral displacement of the chassis side members in relation to one another improve the rigidity of the chassis frame. Bogie trucks are subjected to high lateral forces when cornering. This applies mainly on sharp corners on surfaced roads or on rutted surfaces at high axle loads. The cause of this is the bogie striving to travel straight ahead even when the front wheels are turned.

When a truck is towing a trailer, lateral forces will occur in the rear overhang during cornering. An underslung cross member for a tow hitch also induces a certain amount of torsion in the rear overhang. A trailer gives rise to vertical bending forces in the rear overhang, particularly when braking.

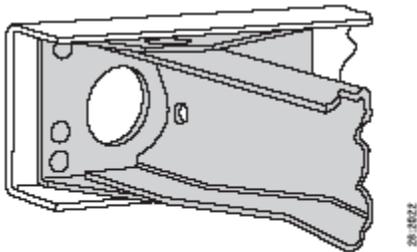


Lateral forces in rear overhang.

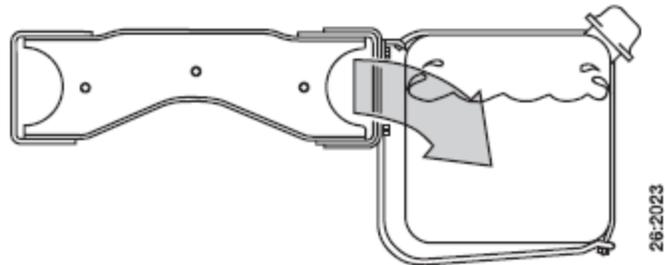
To ensure strength and rigidity in the rear overhang, it should be equipped with a sufficient number of cross members. If the rear overhang is extremely long, diagonal reinforcing stays may also be advisable. The requirements for cross members and diagonal stays depend on the length of the rear overhang and also on the strengthening effect of the body on the rear overhang as well as the requirement for any towing equipment.

Torsional forces (Static):

When driving on uneven road surfaces, the chassis frame is exposed to large torsional forces. The front section behind the cab is torsionally flexible, while the rear section at the rear axle or bogie is torsionally rigid. This torsional flexibility provides the chassis with good mobility at the same time as ensuring adequate strength. Torsional flexibility is achieved by designing the side members and cross members as U-sections and securing them to one another so that the torsional flexibility of the open U-sections is not limited.



Crossmember attachment to sidemember.



Torsional force in chassis frame sidemember.

Heavy components such as fuel tanks and compressors, mounted on the chassis frame members give rise to high torsional forces. Twisting of the side members is prevented by additional cross members or stays. The difference between wheel load on the left-hand and right-hand side of each axle should not be greater than 3 per cent of the total axle weight.

FAILURE MODES:

FATIGUE FAILURE-

Many m/c parts are subjected to varying stresses caused by repeated loading and unloading. Parts subjected to such loading frequently fail at a stress much smaller than the ultimate strength determined by a static tensile test.

When a ductile steel specimen is subject to a gradually increasing load, yielding of the specimen is evident before actual failure occurs. But a specimen of the same material that is subjected to stress reversal fails suddenly without any plastic deformation or any other warning. Thus the fatigue failure of ductile steel is similar to static failure of a brittle material.

At first it was thought that repeated application of load changed the crystalline structure of the material, but we now know that this is not true. Fatigue failure is explained more satisfactorily by the localized stress theory, which is based on the stress concentrations.

CRACK AND ITS PROPAGATION-

One possible definition of crack – which is based on the most important effect of crack, and which has structural viewpoint is –

“In case of a structural part, that material discontinuity, developed on the effect of stresses arising from the manufacturing process and/or from the service, can be called a crack, which causes reduction in the load bearing capacity (service strength) of the structural element.”

Stress distribution in chassis frame members:

The forces acting on the chassis frame give rise to tensile and compressive stresses in the chassis frame members. Vertical deflection gives stress distribution as illustrated in the figure.

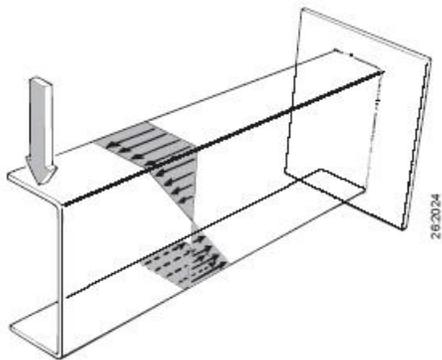
The arrows on the member show the magnitude and the direction of stress. Stress is greatest in the flanges and tapers off towards the symmetry line of the member, where stress is zero. Above the symmetry line, the member is exposed to tensile stress and below it, it is exposed to compressive stress.

In the case of horizontal deflection, stress distribution is as illustrated in the figure. Stress is greatest at the free edge of the flange. Stress tapers down to zero at the symmetry plane.

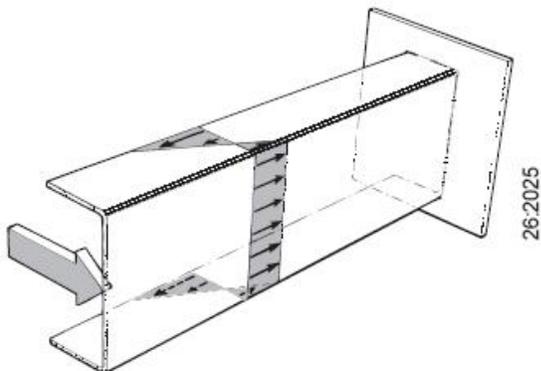
On this side of the plane, the member is exposed to compressive force.

The frame members are exposed to vertical and horizontal deflection at the same time. The stresses from both these deflections are added together. In addition, the frame members are exposed to twisting. The figures show that the flanges, especially the free edge of the flange, are exposed to the highest stresses. This means that this part is especially sensitive to damage such as cracks and slag inclusions in welds.

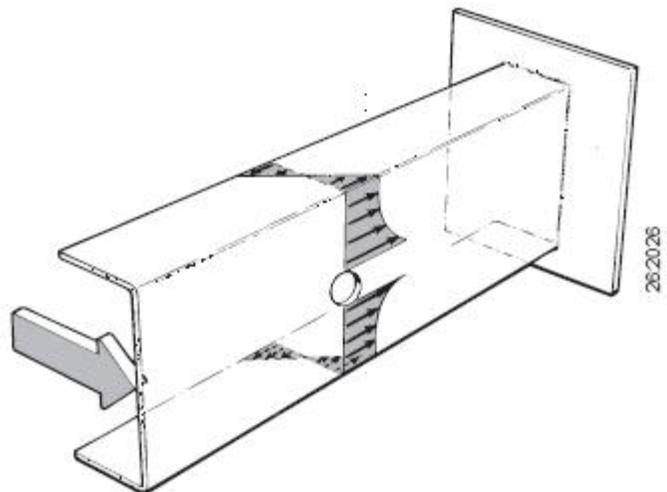
For this reason, all attachments of bodywork and components to the chassis frame should be made with bolted joints in the **side member webs**. The figure shows the stress distribution in a member, which has a hole in the web and is subjected to a horizontal load. In order to restrict stress concentrations in the web, holes should be drilled at a certain minimum distance from the flange and with a certain spacing, see section entitled "**Drilling holes**".



Stress distribution caused by vertical bending.



Stress distribution caused by horizontal bending.



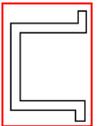
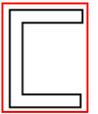
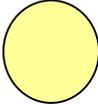
Horizontal deflection of member with a hole in the web.

- Torsional deflection of the frame due to out of phase loading, such as when one wheel drops into a pothole or strikes a bump, is resisted by the longitudinal beam and lateral torsional capabilities of the side members. Open sections such as channel shapes have inherently low torsional stiffness. Again, cross members are required to exert a strong stabilizing influence and add to the torsional rigidity of the side-member.
- Warping or twisting of individual side members is due mainly to cantilevered component mountings such as, engines, fuel tanks, batteries, and suspension attachments. The effect of twist is overcome with proper cross-member placement. Vibration of side-member mounted components, and the resulting effect on the side-member are considered more important than the static loads they impose on the side-members.
- The cab transmits load to the frame due to its own weight and is of limited structural value to the frame. Generally the frame must be rigid enough to avoid large deflection in this area as the cab construction limits its ability to withstand large deflections.
- The front and rear suspension systems load the frame by reacting to the payload. The rear suspension supports the major share of the payload and imparts braking and power torque to the frame. Because the suspensions are mass spring systems with natural frequencies, the natural beaming frequency of the frame must be outside the range of suspension frequency to avoid any possibility of resonance. Also, front and rear suspension roll rates are generally different, so that unequal forces are introduced in the frame structure between front and rear, tending to produce torsional deflection in the frame.

It should be noted that, ladder type of frame construction is designed to offer good downward support for the body and payload and at the same time provide torsional flexibility, mainly in the region between the GB cross member and the cross member ahead of the rear suspension. This chassis flexing is necessary because a rigid frame is more likely to fail than a flexible one that can “eave” when the vehicle is exposed to arduous conditions. A torsionally flexible frame also has the advantage of decreasing the suspension loading when the vehicle is on uneven surfaces.

A truck or other vehicle rolling across a beam or girder constitutes a system of concentrated loads at fixed distances from one another. For beams carrying only concentrated loads the maximum bending moment occurs under one of the loads. The largest of these various values is the maximum moment that governs the design of the beam.

BEAM SECTIONS TO BE USED FOR WITHSTANDING THE LOADS:

Hollow section	– highest bending resistance.	
Box section	– higher bending resistance.	
I section	– high bending resistance.	
Cap section	- great bending resistance.	
C or Channel section	– good bending resistance.	
Circular section	- lesser bending resistance	

FACTS ABOUT ‘C’ SECTION AND ‘I’ SECTION:

The frame resists vertical and lateral bending through the side-members.

- As the primary load input is vertical, due to the payload effect, the side-members are designed first to resist this load, and second to resist the lateral inputs
- Side-members are designed as longitudinal beams.

“ An I shaped member would perform this task more efficiently than a channel shaped member. However an I shaped member has several limitations, fabrication of contoured profiles are difficult, manufacturing costs are high, and attachment of components and cross-members is complicated.

Channel sections have one unique property; the shear center is not coincident with the centroid:

On any section of beam subjected to other than pure bending, there exist shearing stresses. These stresses create internal shearing forces whose resultant must be equal, opposite and collinear to the external shear; otherwise the bending is accompanied by twisting of the beam. Bending without twisting occurs only when the resultant of the shearing forces passes through the shear center. ***“The shear center is defined as the point in the cross-section of a beam through which the plane of transverse bending loads must pass through so that the beam will bend without twisting”.***

Consider the channel section used as a cantilever. The resisting forces consist of the resisting vertical shear V_r considered as acting through the web of channel, the resisting couple M_r composed of Tensile and compressive forces T & C , and the horizontal flange forces H , which are the resultants of the shearing stresses in the flanges.

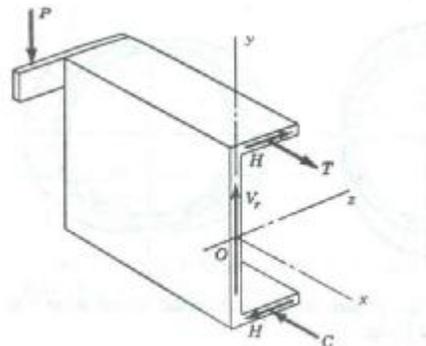


Figure 13-19 Free-body diagram of channel section.

The six equations of equilibrium are

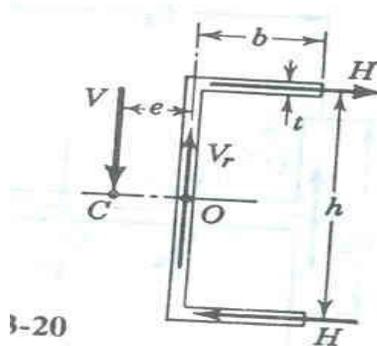
1. $\Sigma F_x = 0$, T & C balance each other
2. $\Sigma F_y = 0$, resisting vertical shear V_r balancing the vertical shear V caused by P
3. $\Sigma F_z = 0$ equal and opposite flange forces balance each other (h)
4. $\Sigma M_y = 0$ vertical loads cause no moment, moments of T & C cancel each other, as do the flange forces.
5. $\Sigma M_z = 0$ applied bending moment M is balanced by the resisting moment supplied by M_r , supplied by T and C .
6. $\Sigma M_x = 0$, this condition must be satisfied to prevent the beam from twisting as it bends. It can be satisfied only if the applied load balances the moments of the shearing forces developed over the section.

$$H = \frac{1}{2}(Vhtb)/2I * b$$

$$= Vhtb^2/4I$$

$$e = Hh/V$$

$$= h^2b^2t/4I$$



Channel sections have this unique property; the shear center is not coincident with the centroid. Any vertical load not oriented to pass through the shear center, which lies outside the section, will produce a rotational displacement. Fortunately frames have cross members. Their bending stiffness resists the rotational tendency of the channel shaped side member, thus stabilizing the channel section and allowing full development of its beam efficiency.

CONDITIONS WITH HIGH STRENGTH LOW SECTION MODULUS FRAME:

When a frame is loaded in bending, internal stresses are produced within each rail to oppose the forces trying to bend the frame. The size and shape of the frame rail determine the internal stresses caused by a given amount of loading. As stated previously, the larger the section modulus value of the frame the lower the internal stresses. It is possible to support the same loading with a frame of small section size and shape as with a section of larger section modulus by allowing the maximum internal stresses within the rails to become very high.

The Resistant Bending Moment for both the small frame and large frame can be made equal. This will require the use of a heat treated high tensile steel frame, which can allow internal stresses to rise to value up to 110,000 psi.

The major advantage to this type of frame is to save weight on bare chassis so maximum payload can be loaded on freight carrying trucks where each pound carried is translated to money earned.

While the size and shape of the frame rail section determine the internal stresses under loading, they also determine how much the frame will bend under a given load. A low section modulus high strength frame will bend and flex to a much greater degree than a higher section modulus frame under same load.

The strength of material is not the only criterion that must be considered in designing structures. The **stiffness of a material** is frequently of equal importance. To a lesser degree, mechanical properties such as hardness, toughness and ductility determine the selection of a material.

The following behavior characteristics of frame are of prime importance:

1. **Deflection of structure** at different loads
2. Intensity of load that will produce the first appreciable **buckling deformation**
3. Intensity of load that will produce the first appreciable **permanent set or yielding**
4. Effect of **cyclic loads on fatigue strength**.

OTHER FACTORS AFFECTING THE FRAME DESIGN:

Chassis Frame Vibrations:

If a mass is subjected to oscillation, which has same frequency as the natural frequency of the mass, resonance occurs. Chassis frame vibrations are a result of resonant vibrations in the chassis/body unit, with the oscillation originating from the wheels. Chassis frame oscillation causes discomfort if the amplitude (size) of the oscillation is sufficient and damping is insufficient.

As a general rule, natural frequency is between 6.0 and 6.5Hz. At a speed of 70km/h, run out on the wheel will cause oscillation of this frequency, which makes the speed range around 70km/h critical. Chassis frame oscillation can also occur at half this speed, i.e. 35km/h.

Allowable run outs for the wheels:

	Radial run-out (mm) measured on the tread	Axial run-out (mm) measured on the sidewall
Front wheels	1	4
Rear wheels	1.0 - 2.0	4

Chassis frame oscillation means that vibration from the wheels is too great in relation to the chassis/body unit.

RIGIDITY:

Rigidity has a large effect on the tendency of a system to oscillate. It is obviously more difficult to cause a rigid construction to oscillate than a flexible one. As rigidity increases, the natural frequency of a certain part of the bodywork and truck increases. It is preferable for the natural frequency to be so high (>25Hz) that vibration cannot cause discomfort. A rigid construction does not allow such large oscillation, which is good thing.

This should however not be confused with a spring which is intended to isolate a moving part from the rest of construction.

DAMPING:

Without integrated damping, truck would oscillate freely. In addition to dampers, which are fitted to the system, there is also friction damping at all points where surfaces move in relation to each other. This friction damping, which arises where there is relative movement increases with movement and friction. There is a large range of possibilities to create damping in bodywork. The most effective damping is achieved through the relative movement between the main frame and the auxiliary frame.

STABILITY:

In trucks with air suspension e.g. tipper trucks, crane trucks, dumpers etc., extra care must be taken when load handling. When load handling with tippers and dumpers, the bogie air bellows must be vented of air.

Design and Validation of Frame:

Design of Frame means optimizing the sections of the FSMs at various locations of the Frame according to the strength/load requirements and integrating / reinforcing with cross members at desired locations along side the Frame.

Methods to achieve the Design:

1. Hand calculation and M/s Excel programming
2. Using software like CATIA, IDEAS, and ANSIS...etc.
3. Component Testing in Laboratory / Vehicle Evaluation Testing in real time conditions.

Procedures to be followed:

COLLECTION OF DATA:

- q Dimensional details of the Vehicle
 - § Overall length of the vehicle
 - § FOH
 - § Distance b/w 1st and 2nd Front axles
 - § Wheel Base
 - § Bogie Spread or Distance b/w 1st and 2nd Rear axles
 - § All Spring Spans
 - § ROH

- q Load/distance/CG details of the vehicle
 - § Cab
 - § Engine & Gear Box
 - § SWC
 - § Battery Carrier
 - § Fuel Tank1
 - § Fuel Tank2
 - § Tip Arm
 - § Hydraulic tank for tip gear
 - § Crew cab
 - § AGB (for 4X4 / 6X6)
 - § A general UDL type load for unidentified/ignored loads
 - § Body and Payload (5th wheel imposed load)
 - § Body non-UDL (scow end or over cab skip)
 - § Material properties of the Frame

- q Factor of Safety details for various conditions (Overloading, Braking, Cornering, and Articulation...etc)

1.RIGID:

- a. Vertical Bump 2.75 or 3g
- b. Vertical Bump 2g + 0.6g footbrake
- c. Vertical Bump 2g +0.25g hand brake

2.TIPPER:

As above plus

- a. 1.6 X Load just lifted off the Chassis
- b. 1.6 X Tipping to 30° without load slip
- c. Tipping to 45° without load slip

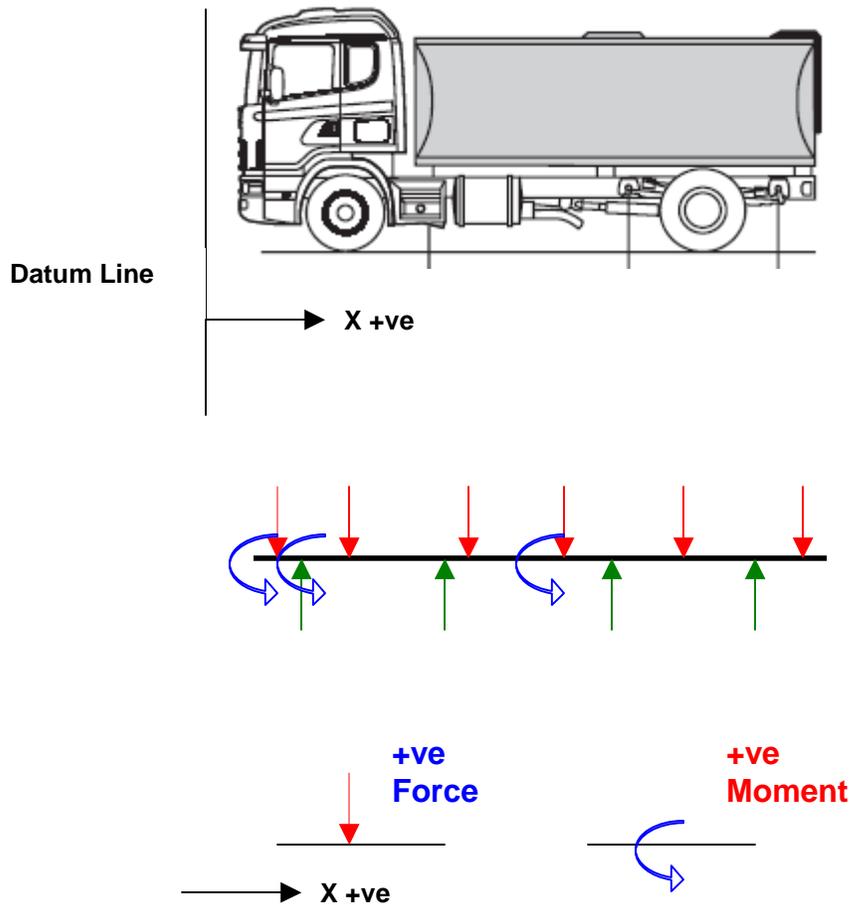
3.ARTICULATED:

As rigid plus

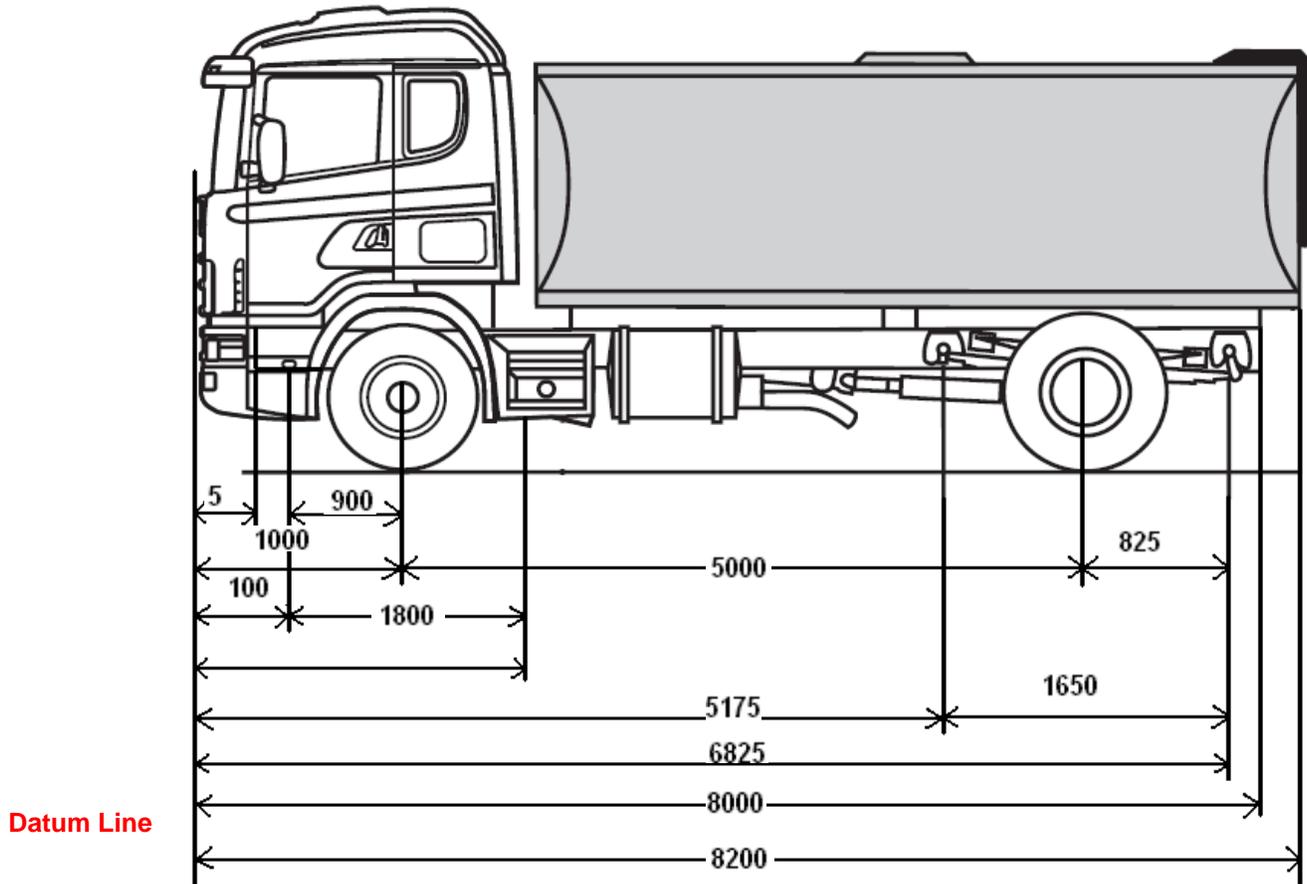
- a. Braking to maximum extent possible with non-functional trailer brakes.

CALCULATION OF BENDING MOMENTS:

Sign conventions:



Collection of Data:



- Find out the total forces, both vertical and horizontal and also the moments acting on the nodes.
- Then calculate the total bending moment produced by the forces about the reference point.
- Make a graph using the nodal values of the Bending Moment.
- Also in the graph draw the allowable Bending Moment (**S x Z**) limits.
- Make sure the Bending Moment generated is well within the allowable limits.
- Design / Select sections (Z) and material for the frame to withstand all the loads within the allowable limits.

$$M_{\max} / I = S_{\text{allowable}} / y_{\max} = E / R$$

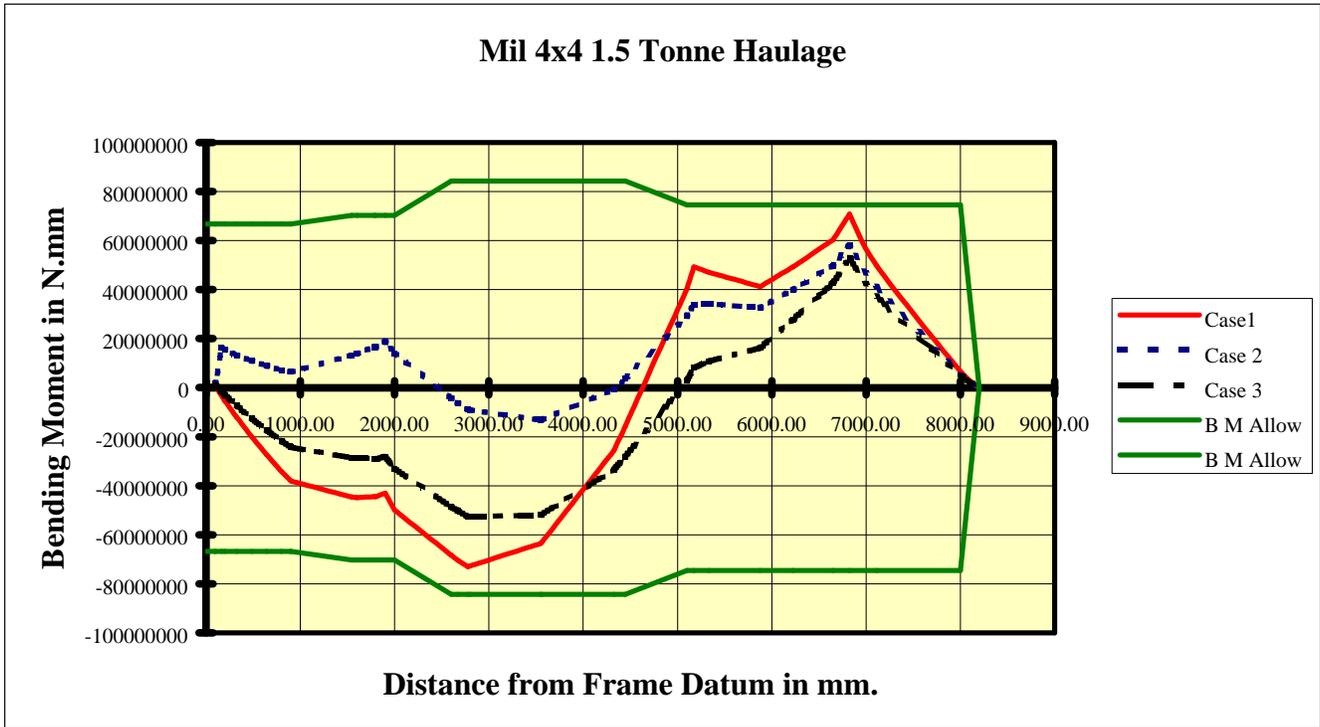
$$\text{Design } Z = M_{\max} / S_{\text{allowable}}$$

where $Z = I / y_{\max}$

Distance From Datum	Bending Moment	Bending Moment	Bending Moment	Frame Allowable	Frame Allowable	Case 3 %ge
Distance	Case1	Case 2	Case 3	B M Allow	B M Allow	Allowable
5.00	0	0	0	66777183	-66777183	0.00
5.00	0	0	0	66777183	-66777183	0.00
5.00	0	0	0	66777183	-66777183	0.00
95.00	580948	387299	387299	66777183	-66777183	0.58
95.00	580948	387299	387299	66777183	-66777183	0.58
100.00	682546	1642327	1070961	66777183	-66777183	1.60
100.00	682546	1642327	1070961	66777183	-66777183	1.60
164.15	-3256855	16275890	-1560332	66777183	-66777183	2.34
164.15	-3256855	16275890	-1560332	66777183	-66777183	2.34
200.00	-5330729	15496693	-2945722	66777183	-66777183	4.41
200.00	-5330729	15496693	-2945722	66777183	-66777183	4.41
323.30	-11948199	13326852	-7280701	66777183	-66777183	10.90
323.30	-11948199	13326852	-7280701	66777183	-66777183	10.90
482.46	-19923616	10903477	-12498689	66777183	-66777183	18.72
482.46	-19923616	10903477	-12498689	66777183	-66777183	18.72
641.61	-27333071	8857412	-17339368	66777183	-66777183	25.97
641.61	-27333071	8857412	-17339368	66777183	-66777183	25.97
800.76	-34176562	7188655	-21802737	66777183	-66777183	32.65
800.76	-34176562	7188655	-21802737	66777183	-66777183	32.65
893.33	-37828048	6437451	-24179500	66777183	-66777183	36.21
893.33	-37828048	6437451	-24179500	66777183	-66777183	36.21
900.00	-38071680	6396238	-24337776	66777183	-66777183	36.45
900.00	-38071680	6396238	-24337776	66777183	-66777183	36.45
1545.00	-44599644	13185035	-28592756	70291772	-70291772	40.68
1545.00	-44599644	13185035	-28592756	70291772	-70291772	40.68
1600.00	-44801976	13886434	-28778358	70291772	-70291772	40.94
1600.00	-44801976	13886434	-28778358	70291772	-70291772	40.94
1781.67	-44481189	16597003	-28869777	70291772	-70291772	41.07
1781.67	-44481189	16597003	-28869777	70291772	-70291772	41.07
1800.00	-44395670	16932777	-28829669	70291772	-70291772	41.01
1800.00	-44395670	16932777	-28829669	70291772	-70291772	41.01
1800.00	-44395670	16522633	-29042438	70291772	-70291772	41.32
1800.00	-44395670	16522633	-29042438	70291772	-70291772	41.32
1900.00	-43046305	18911115	-28251469	70291772	-70291772	40.19
1900.00	-43046305	18911115	-28251469	70291772	-70291772	40.19
2000.00	-49869650	14032903	-33001181	70291772	-70291772	46.95

2000.00	-49869650	14032903	-33001181	70291772	-70291772	46.95
2000.00	-49869650	14032903	-33001181	70291772	-70291772	46.95
2000.00	-49869650	14032903	-33001181	70291772	-70291772	46.95
2600.00	-68393873	-4182775	-48573715	84350127	-84350127	57.59
2600.00	-68393873	-4182775	-48573715	84350127	-84350127	57.59
2670.00	-70349022	-6148466	-50241689	84350127	-84350127	59.56
2670.00	-70349022	-6148466	-50241689	84350127	-84350127	59.56
2775.00	-72977367	-8894084	-52540732	84350127	-84350127	62.29
2775.00	-72977367	-8894084	-52540732	84350127	-84350127	62.29
2800.00	-72761138	-9100014	-52585685	84350127	-84350127	62.34
2800.00	-72761138	-9100014	-52585685	84350127	-84350127	62.34
3550.00	-63515213	-13118112	-51928672	84350127	-84350127	61.56
3550.00	-63515213	-13118112	-51928672	84350127	-84350127	61.56
3558.33	-63131805	-13000877	-51747347	84350127	-84350127	61.35
3558.33	-63131805	-13000877	-51747347	84350127	-84350127	61.35
4325.00	-25635860	-733596	-33583784	84350127	-84350127	39.81
4325.00	-25635860	-733596	-33583784	84350127	-84350127	39.81
4446.67	-15587561	3760850	-28064970	84350127	-84350127	33.27
4446.67	-15587561	3760850	-28064970	84350127	-84350127	33.27
5100.00	40264344	29158020	2832915	74509278	-74509278	3.80
5100.00	40264344	29158020	2832915	74509278	-74509278	3.80
5175.00	49201990	33757561	8063916	74509278	-74509278	10.82
5175.00	49201990	33757561	8063916	74509278	-74509278	10.82
5335.00	47029925	34231372	10871864	74509278	-74509278	14.59
5335.00	47029925	34231372	10871864	74509278	-74509278	14.59
5875.00	41264588	32637267	16159151	74509278	-74509278	21.69
5875.00	41264588	32637267	16159151	74509278	-74509278	21.69
6223.33	49277805	39957878	27664868	74509278	-74509278	37.13
6223.33	49277805	39957878	27664868	74509278	-74509278	37.13
6650.00	60329881	49749314	42582557	74509278	-74509278	57.15
6650.00	60329881	49749314	42582557	74509278	-74509278	57.15
6825.00	70757135	58224735	52905513	74509278	-74509278	71.01
6825.00	70757135	58224735	52905513	74509278	-74509278	71.01
7111.67	49784685	41204703	37347659	74509278	-74509278	50.12
8000.00	6736200	5702122	5119193	74509278	-74509278	6.87
8200.00	0	0	0	0	0	0
8200.00	0	0	0	0	0	0

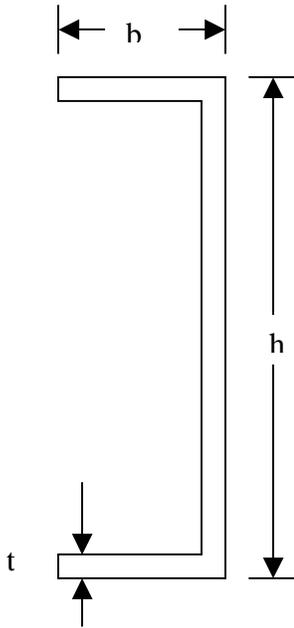
BENDING MOMENT DIAGRAM



SENSITIVITY ANALYSIS:

OBJECTIVE:

TO ANALYSE THE SENSITIVITY OF FRAME **WEB HEIGHT** TO THE CHANGE IN **THICKNESS** AND VICE-VERSA FOR THE SAME **SECTION MODULUS** AND **FLANGE WIDTH**.



LET,
 t = frame thickness
 b = width of flange
 h = frame depth

$$\text{Moment of inertia (MI)} = \frac{(bh^3)}{12} - \frac{((b-t)*(h-2t)^3)}{12}$$

$$\text{Section modulus (Z)} = \frac{2*(b*h^3)}{12*h} - \frac{2*((b-t)*(h-2t)^3)}{12*h}$$

$$\text{Section modulus Z} = \frac{(b*h^2)}{6} - \frac{((b-t)*(h-2t)^3)}{6*h}$$

$$Z = \frac{(b*h^2)}{6} - \frac{(b*(h-2t)^2*(h-2t))}{6*h} \quad \{t \ll b \quad t \ll h \quad \text{thus, } (b-t)=b \quad (h-2t)=h\}$$

$$Z = \frac{(b*h^2)}{6} - \frac{(b*(h-2t)^2)}{6} \quad \{t \ll b \quad t \ll h \quad \text{thus, } (b-t)=b \quad (h-2t)=h\}$$

$$Z = \frac{(b*h^2)}{6} - \frac{(b*(h-2t)^2)}{6}$$

$$\frac{Z*6}{b} = (h^2) - ((h-2t)^2)$$

$$K = (h^2) - ((h-2t)^2)$$

Section modulus and flange width being constant K is constant parameter.

Taking h as dependent parameter and t as independent parameter,

Differentiate above equation

$$0 = 2 * h * \frac{\delta h}{\delta t} - 2 * (h-2t) * \left(\frac{\delta h}{\delta t} - 2 \right)$$

$$\Rightarrow h * \frac{\delta h}{\delta t} = (h-2t) * \left(\frac{\delta h}{\delta t} - 2 \right)$$

$$\Rightarrow h * \frac{\delta h}{\delta t} = (h-2t) * \frac{\delta h}{\delta t} - 2 * (h-2t)$$

$$\Rightarrow h * \frac{\delta h}{\delta t} = h * \frac{\delta h}{\delta t} - 2t * \frac{\delta h}{\delta t} - 2 * h \quad \{ t \ll h \text{ à } (h-2t) \approx h$$

$$\Rightarrow 0 = -2t * \frac{\delta h}{\delta t} - 2 * h$$

$$\Rightarrow 2t * \frac{\delta h}{\delta t} = -2 * h$$

$\delta h = - \frac{h}{t} \delta t$

this concludes that with increase in web height, thickness of frame can be reduced with this relation an approximate value can be obtained.

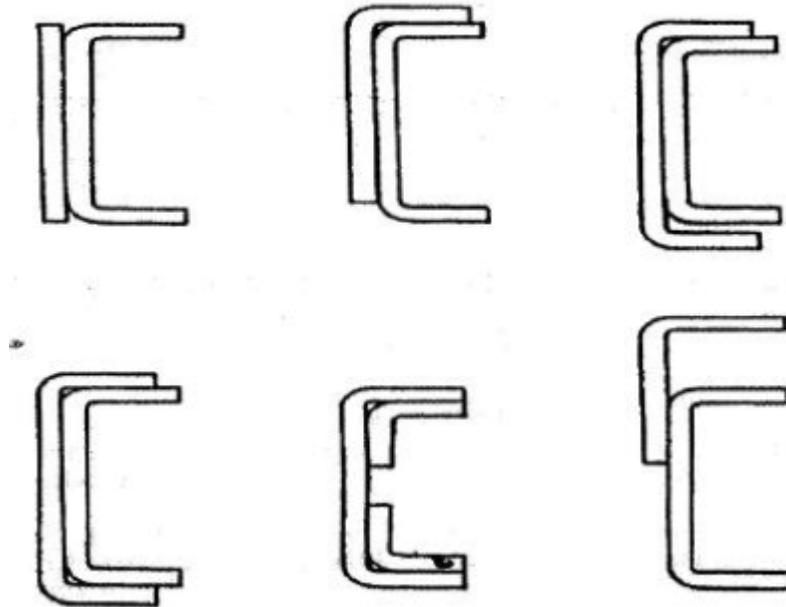
With increase in web height and decrease in thickness, chances of buckling increases but buckling will take place only in case

- There is axial compressive loading (quite few chances in chassis) frame
- High slenderness ratio (but in frame the free length is quite less because of support from cross members)

Thus in this case, buckling can be almost neglected.

REINFORCEMENTS:

FLITCH CONCEPT:



Cross sections of typical reinforcement methods

CROSS MEMBER CONCEPT:

Cross-members have been described as augmenting the torsional stiffness and lateral bending stiffness of the side-members and providing the required resistance to longitudinal loading of the frame. Their, number and points of attachment to the side-member, are determined by considerations for power train, suspensions and cab systems. There are no standard designs for cross-members. Their type of design is dependent on the load resisting characteristics required by the frame structure. The cross-member designs rely, to a large extent on past experience and packaging considerations.

The mode of loading and accommodation of components dictate the method of attachment of a cross-member to the side member. The three general classifications are:

- Web attachment – connection is made at side-member web
- Flange attachment – connection is made at side-member flange
- Flange and web attachment – connection is a combination of web and flange attachments

Flange mounting of a cross-member is considered the most effective for overall frame rigidity, because it provides the maximum resisting moment arm span. However, flexure in side-member prevents recommendation of the flange mounting method in the high stress areas because of the stress concentration effects of holes.

A wider span of attachment is required with the web attachment to obtain comparable rigidity to that of the flange attachment. This is due to the reduced vertical span and the greater flexibility of the web portion of the rail.

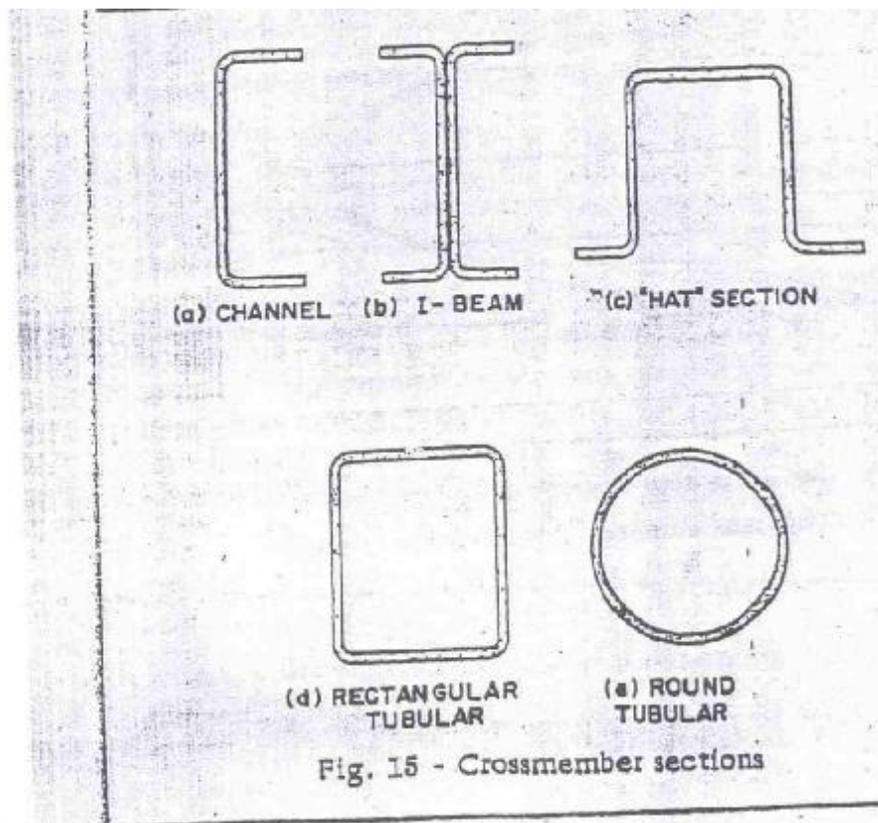
Selection of cross member sectional configuration is dependent upon which load-resistant property predominates at the particular location.

Warping or twisting of individual side members is due mainly due mainly to cantilevered component mountings such as engines, fuel tanks, batteries and suspension attachments.

The effect of twisting is overcome with proper cross-member placement.

A general statement of the different design requirements imposed on typical cross members would be:

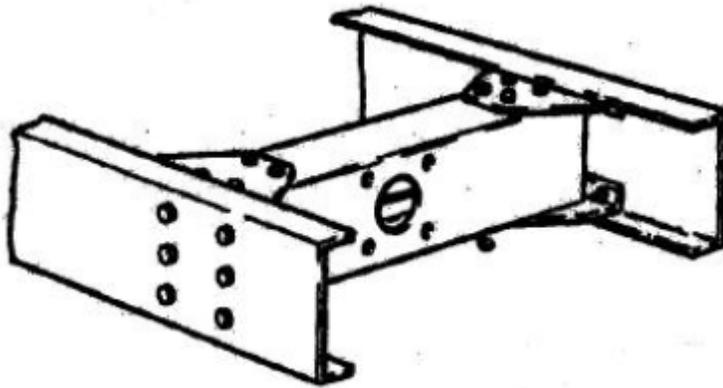
1. Provide support for installation of vehicle components
2. Separate the side members and sustain the dimensional integrity of the frame structure
3. Provide resistance to twisting, torsion and parallelogramming forces applied to frame.



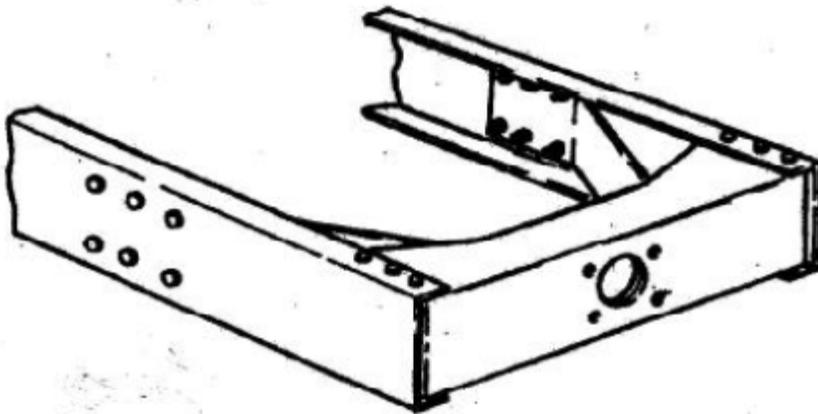
The types of cross member that are fitted to a vehicle can be divided into four basic categories, namely:

1. End of Frame Cross members
2. Rear Suspension Cross members
3. Intermediate Cross members
4. Special Cross members

End of Frame X Members:

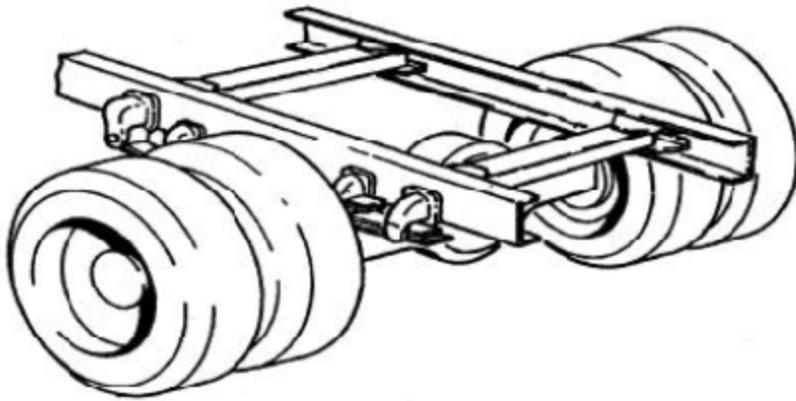


Front End X Member

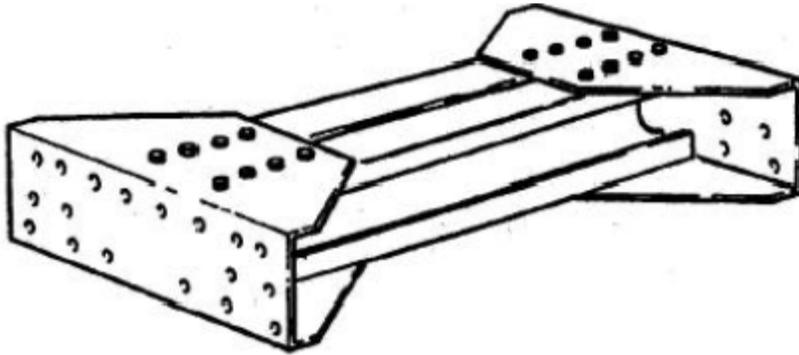


Rear End X Member

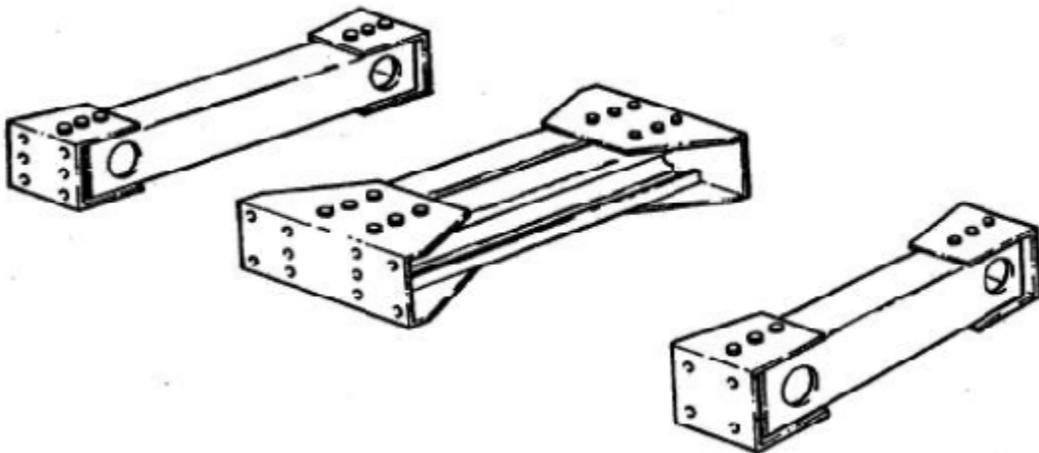
Rear Suspension X Members:



**Single Axle Rear
Suspension X Member**

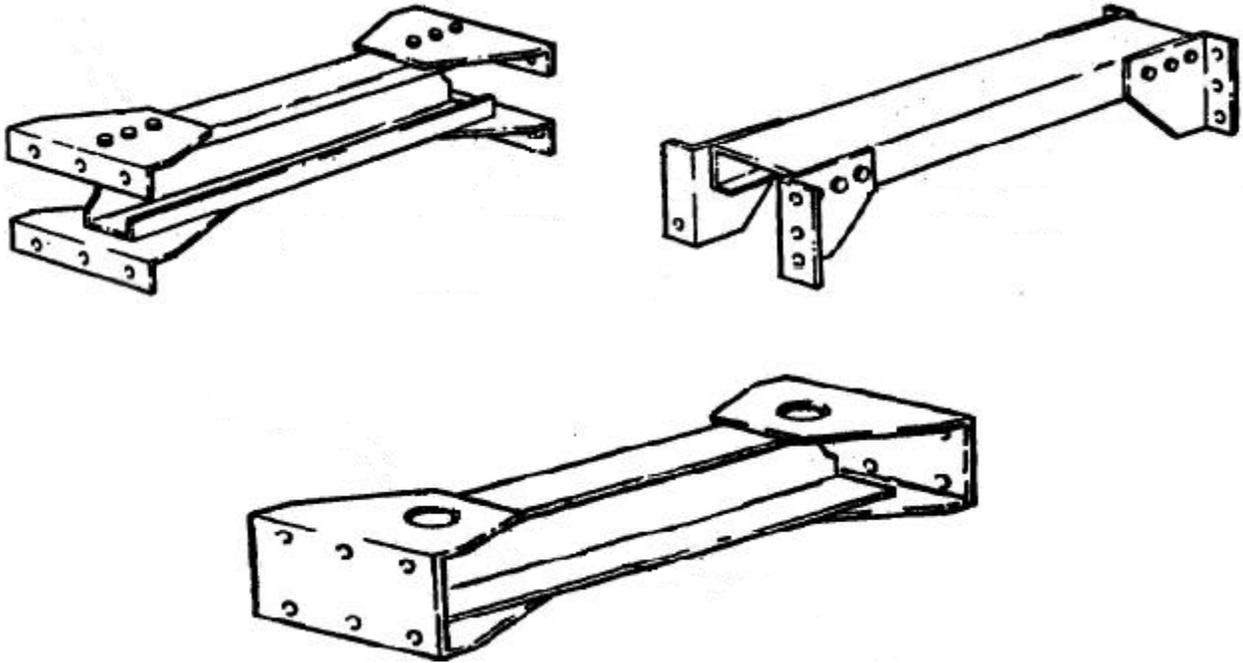


**Multi Axle Bogie
Suspension X Member**

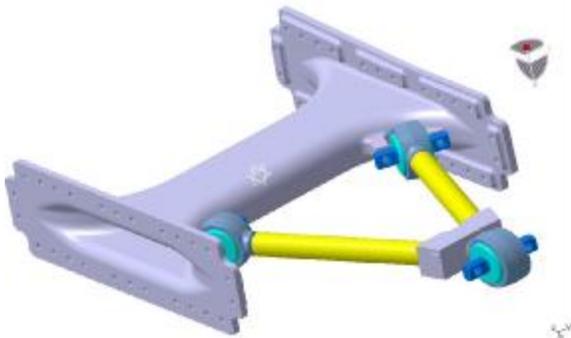


Multi Axle Tandem Suspension X Members

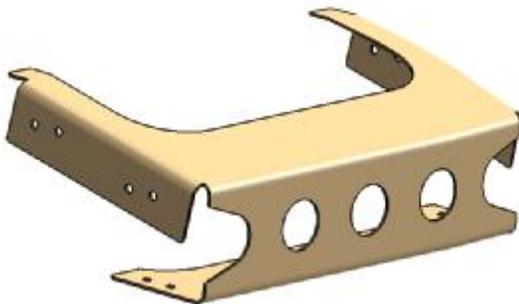
Intermediate X Members:



Special X Members:



**CASTING X-MEM FOR
TRACTOR BOGIE**



**TAPERED REAR X-MEM FOR
TRACTOR AS GUIDE RAMP**

Location of X Members:

- 1.Spring hanger bracket - if not possible - nearest point. Preferable connected by an internal flitch.
- 2.Centre bearing.
- 3.Longest allowable span between cross members to be within 1500 mm.
- 4.Preferable at engine mounting locations. In case not possible, to be located at nearest point of engine / gearbox mounting.
- 5.Local reinforcements required at engine mounting and spring bracket areas depending on stress in these areas.
- 6.Front end must be closed by a cross member. Max distance between cross member and frame side member not to exceed 50 mm.
- 7.The distance between the rear most cross member and rear open end not be exceed 500 mm.
- 8.Provision of clearance at CM joints for pipes / wiring harness - acceptable limit 80 to 100 mm.