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Design of Modular Chassis Frame for Truck Application

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Abstract: **The product variance of heavy commercial vehicles is a central challenge for internationally operating manufacturers due to the interplay of diverse application scenarios, legal requirements and long product life cycles. In order to master the diversity of variants and to ensure the long-term profitability of the company, sustainable variant management is required. Modular systems as a consistent continuation of established module and platform approaches are a promising approach to be able to realize the variants demanded by the market as cost-efficiently as possible and without impairing customer-relevant vehicle characteristics such as driving behavior. The chassis of heavy commercial vehicles, i.e. frames including add-on parts, chassis and axles, are affected by a particularly high number of variants in different sub-areas, i.e. at different system levels. A consistent modular system promises to provide a remedy here in the area of conflict between customer requirements and economic efficiency.**

For the chassis of heavy commercial vehicles, a consistent modular system is to be designed which, in interaction with the overall vehicle architecture, allows the greatest possible reduction in development costs.

This paper focuses on modular Chassis frame design for commercial vehicles and existing approaches to modularization are presented. However, these do not refer to all aspects necessary for the modularization of commercial vehicles. A model for generic package space decomposition is introduced, which supports the creation of essential synergetic effects by identifying hot spots for modularization potentials. Focusing on one specific package sector, different layouts and their characteristics are compared and evaluated in order to reduce internal variance without reducing the market-related external variance.

Keywords: **Commercial vehicle design, modularization, product architecture, Standardization, Vehicle layout, generic package space decomposition**

INTRODUCTION

Modular design, also known as **"modularity in design",** refers to a design approach that subdivides a system into smaller parts or modules that can be independently created and then used in different systems. These modules are standardized and interchangeable, which means they can be mixed, matched, and swapped without any issue. This approach allows designers to create complex products, systems, or processes by combining simpler, self-contained modules.

Modularity is the degree to which a system's components may be separated and recombined, often with the benefit of flexibility and variety in use.

The concept of modularity is used primarily to reduce complexity by breaking a system into no of parts, kits etc.

This modularity is intended to make repairs and maintenance easier, or to allow the vehicle to be reconfigured to suit different functions.

Automotive Chassis Frame is a pressed-steel frame that acts as the skeleton of an automotive vehicle. It is also known as ‘Frame’ and can be compared to a human skeleton since it lays the required structural foundation for a vehicle. The main purpose of automotive chassis is to wear the overall weight of the vehicle in its dynamic and stationery state. Other components of an automotive unit such as axle assemblies, wheels, engine, steering mechanism, transmission, suspension member, and brakes are mounted on the chassis. In earlier times, the mounting process was carried out during the manufacturing procedure and was known as body-on-frame construction. However, with the aid of the latest technology available in the automotive industry, vehicle manufacturers can choose to combine both components in one structural segment. This process is known as unibody construction. Automotive chassis is a critical part of the overall structural integrity of the vehicle since it is essential in several operational aspects including safety, handling, and performance

I. BACKGROUND

The concept of modular design can be traced back to the early days of human civilization when primitive societies started to create tools and structures from interchangeable parts. However, the term "modular design" was only coined in the 20th century, initially being applied in architecture and later on in manufacturing, software design, and various other fields.

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In the mid-20th century, modular design started gaining traction in the manufacturing sector with the advent of mass production. Manufacturers recognized that using standardized parts could increase efficiency, lower costs, and offer customers more variety. This approach was popularized by companies such as Toyota in the automotive industry and IBM in the computing industry.

In recent years, modular design has been further revolutionized by digital technology. Digital modeling and fabrication techniques have made it easier to design, test, and produce modules, while advancements in logistics and supply chain management have facilitated the distribution and assembly of modular products.

2. MODULAR ASSEMBLY KIT EVOLUTIONS

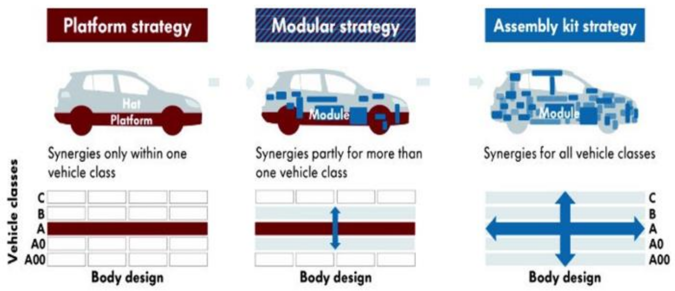


Fig.2 .1 Modular Kit

3. BASIC DETAILS CHASSIS FRAME CONSTRUCTION :

1.Front cross member
2. Front engine cross member
3. Rear Engine cross member
4. Transmission cross member
5. Intermediate cross member
6. Front of Rear axle cross member
7. Rear Suspension cross member
8. Closing cross member

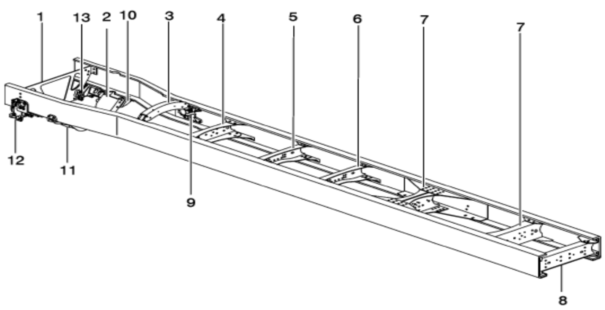
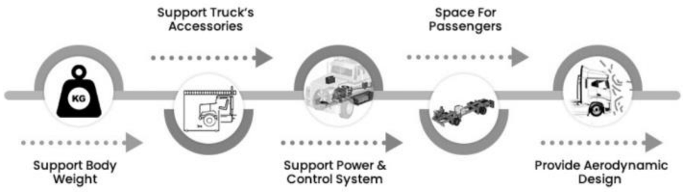


Fig.3 –Chassis frame construction

The ladder frame is one of the oldest, simplest, and most frequently used under-body, separate chassis/frame designs. It consists of two symmetrical beams, rails, or channels, running the length of the vehicle, connected by several transverse cross-members. Initially seen on almost all vehicles, the ladder frame was gradually phased out on cars in favor of perimeter frames and unitized body construction. It is now seen mainly on large trucks.

This design offers good beam resistance because of its continuous rails from front to rear, but poor resistance to torsion or warping if simple, perpendicular cross-members are used.

4. FUNCTION OF TRUCK CHASSIS:



Chassis constructs with long sections called longitudinal members located on either side. The longitudinal members and side members fit together with the help of rivets and bolts. Further, there are generally 5-6 cross members that provide stability and strength to the chassis. For facilitating torsional rigidity, diagonal cross bracing is present in the chassis. Below are some of the key essential roles and functions of the truck chassis.

1) 4.1 Support Body Weight

The manufacturing of chassis technology for a truck relies primarily on the load-bearing capacity of the truck chassis. This capacity supports the body weight of the truck. Brackets provided in the chassis frames help to mount different weights of components like the engine, suspension leaf springs, brake shafts, and others.

2) 4.2 Support Truck's Accessories

An extended part of the truck frame over the front axle is the front overhang, while beyond the rear axle is the rear overhang. Trucks' accessories like clutch, transmission and engine aggregates rivet together into an assembly. Additionally, the front overhang of the truck chassis mounts these components by using rubber blocks.

3) 4.3 Support Power & Control System

All the members used in constructing the chassis frame build with pressed steel. Pressed steel helps to protect the power and control system of the truck from engine vibrations. The members, like rubber blocks, not only support a truck's power system (engine) but also isolate the engine from road shocks. Heavy truck chassis is different from a car's chassis due to the higher loads carried by its power system with continued operations.

4) 4.4 Space for Passengers

The truck chassis working is to maintain the shape of the truck, which further ensures the appropriate space for passengers. Longitudinal members of the chassis frame move upswept in the front & rear, giving proper space for the axle's movement. In addition, this lowers the frame height with a smaller turning circle to give a better steering lock.

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5) 4.5 Provide Aerodynamic Design

With the perfect aerodynamic design, the drag truck chassis reduces the air-dragging force. It helps in enhancing the truck's performance and productivity. The custom truck frames maintain stability and help in providing a contemporary design. Furthermore, the aerodynamic design depends on the types of chassis frames.

5. Different types of modular design"

5.1 - Component Swapping Modularity:
This type is often seen in the manufacturing of cars and computers, where different components or parts, such as engines, wheels, or hard drives, can be easily replaced or upgraded without affecting the rest of the system.
Slot Modularity: This involves a basic frame or structure into which different modules can be inserted or removed. A common example would be a modular sofa, where different sections can be rearranged or replaced according to preference.

5.2 – SECTIONAL MODULARITY:
This type is used when an overall system is divided into smaller sections that can function independently but also work together as a whole. This is often seen in software design, where different sections of the code are designed to perform specific tasks but can also interact to create a more complex program.
Each of these types has its own specific advantages, but they all share the core benefits of modular design: increased flexibility, efficiency, and customization

6. GENERAL PRINCIPE OF MODULAR DESIGN:
Modular design is a fundamental principle used in engineering, architecture, and various other fields. It involves creating systems or products by combining standardized, interchangeable modules or components. This approach is rooted in several key principles that enhance flexibility, efficiency, and adaptability. Here's a breakdown of the general principles of modular design:

6.1 Standardization
Use standardized modules or components that are designed to fit together in a variety of configurations.

6.2 Interchangeability
Components or modules are designed to be easily swapped or exchanged without affecting the overall system.

6.3 Scalability
Modular designs can be scaled up or down by adding or removing

6.4 Reusability
Modules or components can be reused in different configurations or applications.

6.5 Flexibility and Adaptability
Modular systems can be easily adjusted to meet new requirements or integrate new technologies.

6.6 Simplification
The system is broken down into simpler, manageable modules.

6.7 Efficiency
Streamlines production and assembly by using a set of standard modules.

6.8 Modularity
Each module or component is a distinct unit that can function independently or in combination with others.

6.9 Integration
Modules are designed to work seamlessly together within a larger system.

7.GENERAL PROCESS OF MODULAR DESIGN

Modular design is a design approach that breaks down a system into smaller, self-contained units or modules that can be developed, modified, or replaced independently. This approach is widely used in various fields, including software development, architecture, and product design. Here's a general process for modular design:

Define Objectives and Requirements: Determine the goals of the design and the requirements that need to be met. This includes understanding user needs, performance criteria, and constraints.

Identify and Define Modules: Break down the overall system into smaller, manageable modules or components. Each module should have a specific function or purpose and should be able to operate independently from the others.

Design Interfaces: Define how the modules will interact with each other. This involves specifying the interfaces or communication protocols that allow modules to exchange information or integrate seamlessly.

Develop and Test Modules: Create each module according to its design specifications. Testing is crucial to ensure that each module functions correctly both individually and as part of the larger system.

Assemble and Integrate: Integrate the modules into the overall system. This step involves ensuring that the modules work together as intended and that the interfaces between them function correctly.

Evaluate and Refine: Assess the performance and functionality of the complete system. Identify any issues or areas for improvement, and make necessary adjustments to the modules or their interactions.

Maintain and Update: Modular design facilitates easier maintenance and updates. You can modify or replace individual modules without affecting the entire system, which helps in adapting to changes or improving functionality over time.

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Documentation: Document the design, interfaces, and functionalities of each module. This helps in understanding how the system works and in future maintenance or upgrades

8.PRESENT DESIGN APPROACH:

Different segments and application of vehicles, the positions of aggregates vary resulting in change in topology of the vehicle. This in turn adds to no. of parts, increases cost and increased design lead time. Moreover aggregate position is not fixed, which in turn demands new locating position between different wheel bases of same vehicle.

No defined Interfaces: Interacting components often do not have common interfaces, which results in different parts and different assembly procedures which will add to higher design lead time and assembly time. Mounting arrangement for same aggregate may change in different segment of vehicle as per packaging requirement. Thus assembly procedure also varies as per the requirement.

Different vehicle architecture: Between different vehicles segments the overall layout of the vehicle changes. In line with the vehicle, frame geometry like, cross members position, profile, number of cross members, joining arrangement also varies. This results in a completely a new set of components for each vehicle segment which in turn adds to the cost.

No common tooling: Components like side rails, long reinforcements are developed with tool/ Die setup in house. Die modules for these components varies between types of vehicles. This also require number of die modules to be developed which is an additional cost to organization.

Variety of hardware used: - Hardware includes, Nut – Bolts, Screws, Rivets, clinch nuts, Screws, Studs, U – Bolts, Pins, Washers etc. are used to fix different components to the frame as directly on frame or in sub-assemblies. These are defined based on surface finish, grade & pitch which are not optimized as per the requirement, resulting variety of thousands of parts.

Why change is required in present approach?

Customer Specific Needs: Customer is very demanding in terms of his needs, these needs can be specific to market e.g. luxurious cabs for European trucks whereas economic cabs for Asian markets to satisfy the region based needs of customer. Similar way Exhaust muffler for gulf region is vertical but Asian requirement is horizontal. Cater to the specific needs chassis frame needed a new approach because present or conventional approach takes a longer time to address the needs as the design needs to be worked out from scratch1.

Market Scenario: The present market scenario is constantly changing. New legislative requirements are often imposed in various markets for emission, safety and vehicular loads1. In commercial vehicle segment, especially, new vehicle load segments, new vehicle configurations are being created

Competition: Presence of domestic and Global players, pose a bigger design challenge, which challenges the design in terms of cost, quality and reliability in addition to the price pressure posed by competitors1. Moreover, advancements in engineering technology have brought about a number of challenges in the automotive industry including highly diverse customer demands, short product development cycles, and demand for lower production costs.

The present method will not be able to overcome all the above shortcomings. A modular architecture is an effective solution to overcome all the above requirements

9. MODULARITY TECHNIQUES

Designing a modular automotive chassis frame involves applying modularity techniques to achieve flexibility, scalability, and efficiency in production and maintenance. Here are some modularity techniques specifically tailored for automotive chassis frames:

Component Standardization: Use standardized components that can be easily interchanged or reused across different vehicle models. Standardization helps in reducing production costs and simplifying inventory management.

Modular Subsystems: Design the chassis frame in modular subsystems, such as front suspension, rear suspension, and central frame. Each subsystem can be developed, tested, and replaced independently, allowing for easier customization and repair.

Interchangeable Mounting Points: Incorporate interchangeable mounting points or interfaces that allow different modules or components to be attached or detached with minimal adjustments. This technique facilitates easy adaptation to various vehicle configurations.

Scalable Design: Design the chassis frame to accommodate different vehicle sizes or configurations by scaling modular components. For example, adjustable frame segments can be used to create both compact and full-sized vehicles.

Flexible Jigs and Fixtures: Use adjustable jigs and fixtures during manufacturing to accommodate different chassis designs and configurations. This flexibility in production helps in reducing setup times and costs.

Unified Interface Protocols: Implement standardized interface protocols for communication between modular components. For instance, common electrical and hydraulic connectors can simplify the integration of various subsystems.

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High Strength-to-Weight Ratio Materials: Utilize materials that offer high strength-to-weight ratios, such as advanced composites or high-strength steels, to ensure that modular components are both durable and lightweight.

Modular Assembly and Disassembly: Design the chassis frame for easy assembly and disassembly, allowing for quick replacements or upgrades of modular components. This feature is particularly useful for maintenance and repair.

Design for Manufacturing and Assembly (DFMA): Apply DFMA principles to ensure that the modular design is optimized for efficient manufacturing and assembly processes. This includes minimizing the number of parts and simplifying assembly operations.

Scalable Safety Features: Incorporate modular safety features that can be added or upgraded based on vehicle requirements or regulations. For example, modular crash structures or safety cell designs can be tailored to meet different safety standards.

Integration of Advanced Technologies: Design modular components to accommodate advanced technologies, such as electric drivetrains or autonomous driving systems. Modular designs can support the integration of new technologies with minimal modifications.

Customization Options: Allow for customizable options within the modular design, such as different suspension configurations or frame lengths. This flexibility enables manufacturers to offer a range of vehicle variants based on customer preferences.

By applying these techniques, automotive manufacturers can create chassis frames that are adaptable, efficient, and capable of meeting diverse market needs.

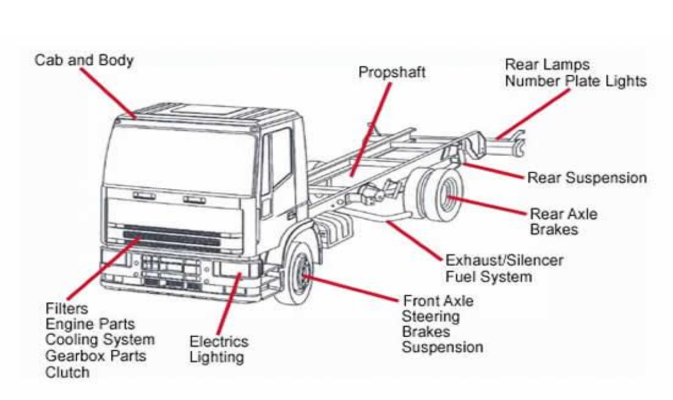

Fig 9.Truck with its aggregates

10. GENERIC PACKAGE SPACE DECOMPOSITION

The vehicle chassis needs split into modules such that the common module stays the same and only the varying module changes, thereby a huge number of part numbers and hence cost can be reduced. An illustrative example of the same in figure no: 10 and 11

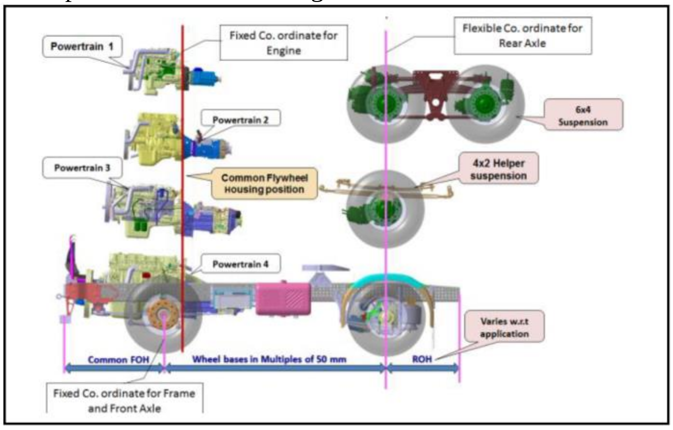

Figure 10.Fixed and Variable coordinates

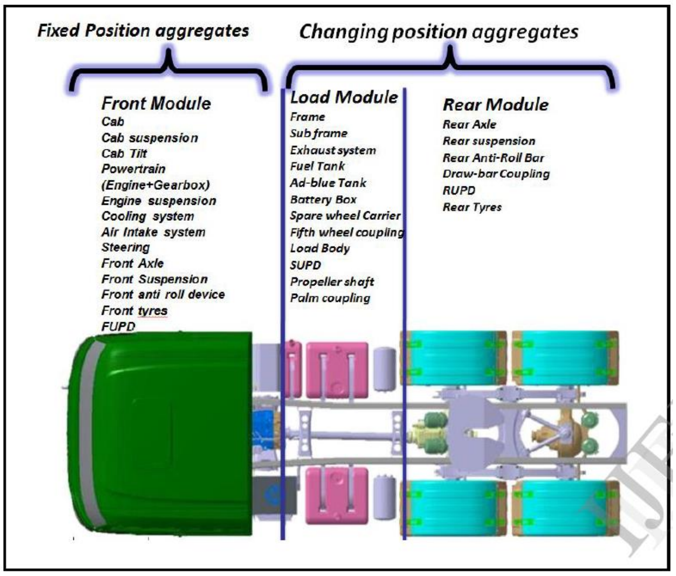

Figure 11.Fixed position aggregates and changing position aggregates

11.1 Modular Components:

Frame Sections: Design the chassis with interchangeable frame sections that can be adjusted for different truck sizes and configurations (e.g., short or long wheelbase).

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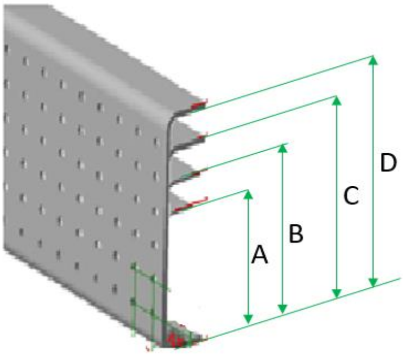
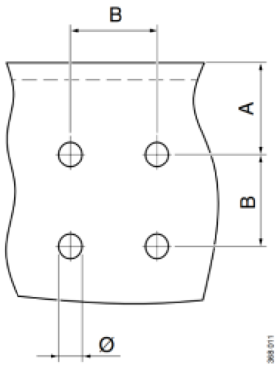


Fig 11.1 Different tonnage vehicle Long members with defined hole pattern

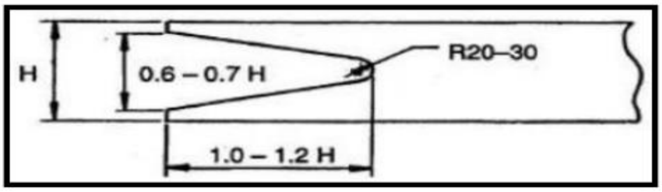


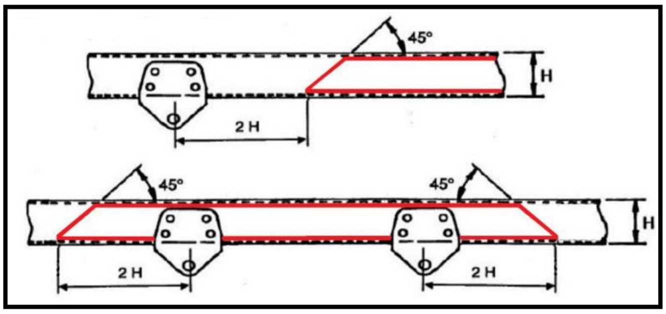
Hole pattern in beam web.

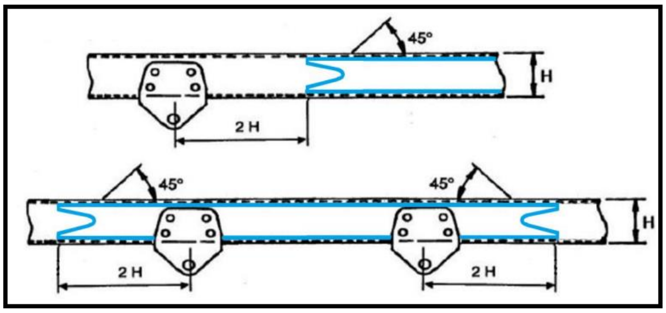
Holes to be added 50x50 mm as per web layout size defined

Suspension Systems: Use modular suspension components that can be swapped based on load requirements or road conditions.

Reinforcement requirement at suspension area







Axle Configurations: Design for different axle setups (e.g., single, tandem, or tridem) to accommodate various load capacities and applications.

In a commercial vehicle, the vehicle wheel base and the axle configuration are the major variables of the vehicle. But the front module comprising the engine, front axle, cooling system, air intake system, cab etc. can be kept modularly

packaged and can be isolated from packaging changes. This in turn reduces the changes that would be required to make a new vehicle which varies in terms of wheel bases, fuel tank capacities, rear suspension options and rear axle changes

The highest stresses in a chassis generally occur where components such as suspension hangers, airbags, torsion bars and rods are mounted so it is critical to ensure chassis joins are not located in these high stress regions. Examples of chassis calculations are provided below. In these examples, the blue line on the loading diagram represents chassis deflection and red line represents bending stress. The further these lines are away from the chassis rail (in the diagram), the greater their respective values are. Nearly all chassis joins require structural reinforcement (which is discussed in detail further below) and additional reinforcement may also be needed in regions of high stress.

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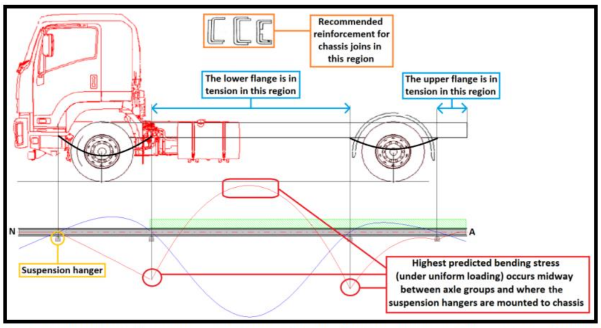


FIGURE 6: BENDING STRESS DIAGRAM FOR A 2 AXLE VEHICLE WITH A SHORT REAR OVERHANG

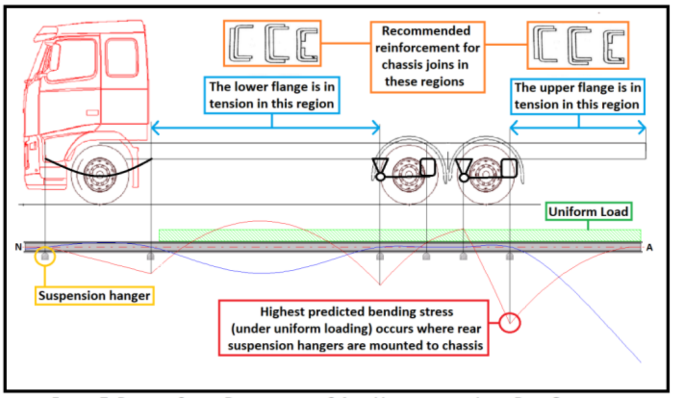


FIGURE 7: BENDING STRESS DIAGRAM FOR A 3 AXLE VEHICLE WITH A LONG REAR OVERHANG

11.2 Interfacing and Connectivity:

Connection Points: Create standardized connection points for modules to ensure compatibility and ease of assembly.

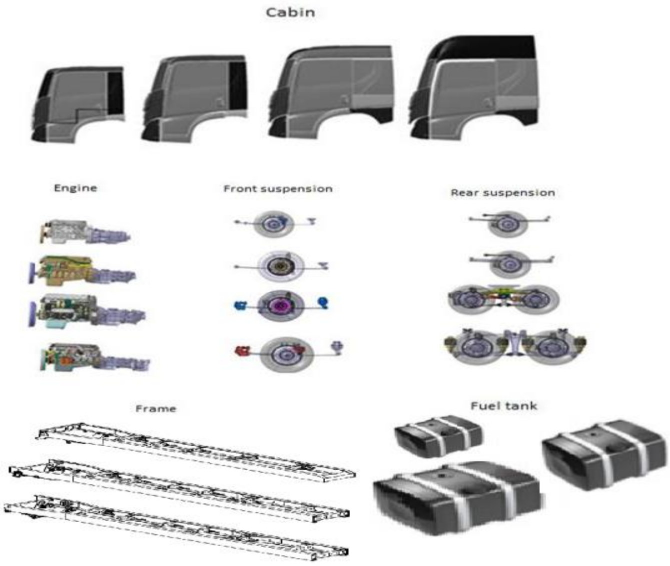


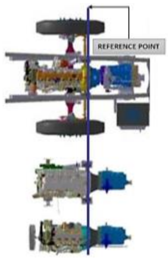
Fig. 11- Modular aggregates which can interchangeable easily

11.3 Customization and Adaptation:

Body Modules: Allow for different body types and configurations (e.g., flatbed, box, refrigerated) to be mounted on the chassis.

Different type's cabin family including fix cab, sleeper cab, and cowl are also fixed from common reference point that is front axle Centre line (Fig. 10). Mounting provision is done on chassis frame to accommodate any cab or cowl variant considering minimal effort on assembly line

Powertrain Options: Design the chassis to accommodate different engine and drivetrain configurations for varying power and efficiency needs. Different horse power engines located at common coordinate position (Refer figure: 7) which helps in interchanging them without doing change in chassis design



11.4 Strength and Durability:

Material Selection: Use high-strength materials that can handle the stresses of different loads and conditions while being lightweight where possible.

Sr. No.	Material	Yield Strength (Mpa.)	Tensile Strength (Mpa.)	Elongation %
1	Fe410	255	410	17
2	DP590	350min.	590min.	24
3	HSS440	280 min.	440min.	27
4	HSLA320	320-380	410-480	24
5	HSLA340	340 min.	410-510	21
6	E34 / BSK34	340	380	27
7	E38 / BSK38	380	450	25
8	E46 / BSK46	460	500	21
9	DP780	480	780 - 900	18
10	DP980	600-800	1030 - 1050	12
11	Domex 650	650	700 - 880	14
12	HS800	700-800	800-900	18

11.5 Cost and Efficiency:

Manufacturing: Streamline manufacturing by using common parts and processes for different truck models and configurations.

Roll forming easier to produce longer lengths than are typically available on a punch press.
Roll forming can provide much closer tolerances than other metal processes.
Roll forming excels in creating parts with uneven legs, and complex holes configurations.
Roll forming ensures that shapes and dimensions are always accurate and uniform.
Roll forming holes modification is easy and cost effective.

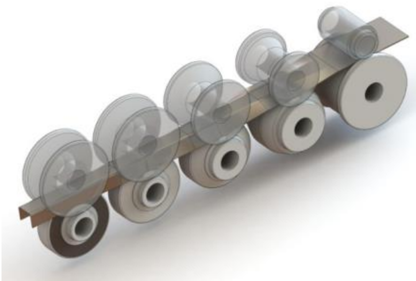


Fig- Roll forming productions

Maintenance: Design for ease of maintenance with components that can be quickly replaced or upgraded without major disassembly.

11.6 Regulations and Standards:

Compliance: Ensure the modular chassis design complies with industry regulations and standards for safety, emissions, and performance.
This approach helps create a versatile truck that can adapt to various roles and requirements over its lifecycle, offering greater value to operators and reducing long-term costs

12. Benefits of Modular Chassis Frames

Absolutely, modular chassis frames are a game-changer in automotive design. Here's a deeper dive into how they embody flexibility, cost savings, and adaptability:

Flexibility

1. **Customizability**: Modular frames allow for various configurations and modifications. This means manufacturers can produce different models of trucks or vehicles from the same base design, adapting the chassis to fit specific needs like cargo capacity, wheelbase, or specialized equipment.
2. **Multi-Use Applications**: The same chassis can be used for different types of vehicles, such as converting a standard truck into a refrigerated vehicle or an emergency response vehicle, by simply changing or adding modules.
3. **Ease of Upgrades**: As technologies evolve, modular frames make it easier to incorporate new features or technologies without a complete redesign of the chassis.

6) **Cost Savings**

1. **Reduced Production Costs**: Standardized components mean that parts can be produced in bulk, reducing the overall cost of manufacturing. Assembly lines become more efficient, and economies of scale come into play.
2. **Simplified Inventory Management**: With interchangeable parts, inventory management becomes more streamlined. Manufacturers can stock fewer types of parts, which reduces warehousing costs and simplifies logistics.
3. **Lower Development Costs**: Developing a new vehicle from a modular chassis frame is typically less expensive than designing an entirely new frame. The modular approach allows for faster prototyping and adaptation, which can significantly cut development costs.

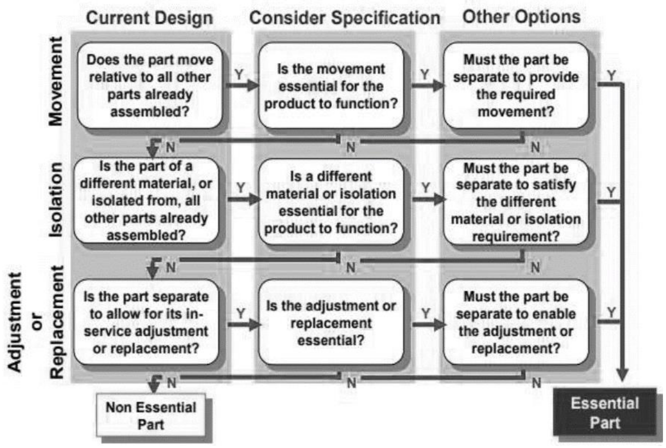


Fig.11 Flow chart to reduce number of parts

Adaptability

1. **Modular Design for Different Needs**: Vehicles can be adapted for various purposes simply by swapping out or adding different modules. For example, a base chassis can be modified to support different types of payloads or specialized equipment, making it suitable for different industries.
2. **Future-Proofing**: As new regulations or technology advancements occur, modular frames can be updated with new modules or components, helping manufacturers keep up with changes without needing a complete redesign.
3. **Enhanced Repair and Maintenance**: Repairing a vehicle with a modular chassis is more straightforward since damaged or outdated parts can be replaced or upgraded individually rather than overhauling the entire frame. This reduces downtime and repair costs.

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13. Predictions for the Future of Modular Design in Manufacturing

Looking ahead, it's likely that modular design will become even more integral to manufacturing:

Greater Adoption across Industries: As more industries recognize the benefits, we're likely to see increased adoption of modular design, not only in traditional sectors like automotive or construction but also in industries such as healthcare, fashion, and consumer electronics.

Advanced Material Usage: The evolution of materials science will provide new opportunities for modular design. As we develop stronger, lighter, and more versatile materials, the possibilities for modular components will expand.

Shift towards Circular Economy: Modular design can play a crucial role in facilitating a shift towards a circular economy, where waste is minimized and resources are reused or recycled. With the ability to easily disassemble and upgrade modular products, manufacturers can reduce waste and create sustainable business models.

The Role of Digital Technology and AI in Advancing Modular Design

Digital technology and AI have already had a major impact on modular design in manufacturing by enabling companies to automate many aspects of production while still maintaining high levels of quality control. As these technologies continue to advance over time, we can expect even greater improvements in efficiency and cost savings for manufacturers who adopt modular designs for their products. Additionally, AI-driven automation will allow companies to quickly adjust their production processes as consumer preferences change over time without having to completely overhaul their operations each time there is a shift in demand.

Though the journey of integrating modular design into the manufacturing industry may present challenges, it's undeniable that the benefits offered by this approach provide a robust foundation for sustainable, efficient, and customer-centric production. As we move forward, embracing modular design could indeed be the key to a successful and sustainable future in manufacturing.

14- Conclusions

The conventional method will not be able to meet the changing requirements and will result in higher lead times and higher cost. To offer greater product variations at lower

Costs, companies can employ a modular strategy that explicitly leverages and reuses same modules in many variants, by building the commercial vehicle using the Light Weight long member and cost saving also it will increased pay load of vehicle

CONCLUSION

1) To optimize the Long member section following sequence of options to be worked out

a) First Option: Web height should be increased which is having highest strength to weight ratio

b) Second option: Increase flange width, which has better strength to weight ratio.

c) Third Option : Increase thickness of section, which has poor strength to weight ratio.

2) Increase in thickness gives more moment of inertia at extreme fibers, which is highest stressed zone.

3) If increased weight in Long member can be compensated at cross members & reinforcements then increase in thickness is best option.

XI. ACKNOLEDGEMENT

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