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Biomechanical Analysis of a Auto Transport Loading Ramp to Produce a Cost Effective Ergonomic Design

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***Abstract*— Numerous studies have indicated the danger while loading vehicles on large automobile transporters or car haulers. Data shows that the automobile transporting industry has the highest employee injury rate of any other industry, including underground coal mining which traditionally has a high rate. One area of high injury is the manual deployment of the loading ramps at the back of the trailer used to drive the cars onto the trailer. When deploying the ramps as designed by the manufacturer, there is a high probably of injury to the driver in the lower back and shoulder area resulting in Musculoskeletal disorders (MSDs) MSD's are soft-tissue injuries caused by sudden or sustained exposure to repetitive motion, force, vibration, and awkward positions. These disorders can affect the muscles, nerves, tendons, joints and cartilage in your upper and lower limbs, neck and lower back.**

Three alternative designs were considered: the Orthopedic Handle, the Stabilized Cylinder, and a Lever designs. Then the final decision was the Orthopedic Handle as being the best design. In developing and testing this design it was found it exceeded expectations with minor adjustments. It was able to manufacture a working prototype from scrap materials for a total cost of $0. In most design criteria evaluation methods, such as decision and Pugh matrices, cost is usually the largest parameter. By this measure alone the design is a dramatic success while keeping the operator's body in a neutral position reduced stress and strain on the body and markedly reducing the probability of operator injury.

Keywords—Ergonomics, biomechanics, car haulers, auto transport,

I. Introduction

Car haulers have been used action since their introduction in 1930's. They were designed to transport a number of cars from either the manufacturer to the car dealer, or even from one dealer to another. There are a wide variety of existing car hauler designs in the world today ranging in size and complexity. The design that will be discussed here is the larger of the designs that is designed to carry ten to twelve cars on a single trailer. Unlike the truck driver who spends nearly all of their time driving, the automobile transport truck driver spends a considerable of time personally loading and unloading the cargo which maybe anything from a small sedan to a large pickup truck or van. The operators therefore perform a unique job function which exposes them to many non-driving hazards. To load and secure the vehicles the driver/operator must perform the following steps:

1. Select vehicles for transport at the loading yard according to a delivery invoice.
2. The different levels on the trailer are set by hydraulic means.
3. Loading skids or ramps are pulled out from tracks on the underside of the trailer and lowered to prepare for the drive on of the vehicle.
4. Vehicles are driven onto the trailer starting with the top row first.
5. The vehicles are secured or "tied-down" to the trailer typically using an antiquated manual chain/ratchet/winch bar system by the driver. At the upper level, these manual ratchet systems must be operated as much as 4 m from ground level, with the driver/operator balancing themselves on a rail that is 4 cm in width. Forces the driver must apply to the winch bar to tie or secure the vehicle to the trailer can be as high as 1250 N [1].
6. The procedure is reversed for unloading the vehicle.

Numerous studies have indicated the danger due to slips and falls while loading and unloading vehicles on the upper ramps/deck area and headrack regions which is directly above the tractor. Data shows that the automobile transporting industry has the highest employee injury rate of any other industry, including underground coal mining which traditionally has a high rate [2]. Insurance records indicate that millions of dollars are lost annually from injuries. [2]. Pay is proportional to speed and efficiency, therefore this encourages the operator to work faster. Familiarity with the car haul-away operation was gained by many hours of observation at the loading areas. A study of an automobile transporters workmen's compensation record indicates that 78% of the accidents occurred from slips and falls from trailers. Most of the injuries are sustained while drivers maneuver around on the car carrier [2]. The National Automobile Transporters Association (NATA) supports the representations of the American Trucking Association (ATA) to the effect that there is a need for substantial investigation and development of factual data with respect to the nature of the driver injuries. NATA is extremely aware of the unusual exposure of drivers to slips and falls during the load/unload procedure [4]. A Bureau of Motor Carrier Safety Report investigated four categories of trucking applications, Tank Vehicles, Auto Transporters, Flat Bed Equipment and Vans. Auto transporters had the highest incidence rate of slips and falls per million driver man hours and higher medical and lost time costs [5]. Safety experts view slip and fall countermeasures as an engineering problem, not a driver training problem. Risk taking and human error are basic human characteristics and must be accommodated in the engineering design. The adverse consequences of driver injury rather than the driver's behavior must be the focus of the engineering design. In 1977, the International Brotherhood of the Teamsters Report found that out of 7,196 injuries reported for the trucking industry, 3,538 were grouped under "vehicle not moving". Of these 3,538, 64.2% or 2,271 were typed as "Falls on the Same or Different levels". Compensation for these types of injuries was $5,227,256 or 12.1% of the total $43,139,600 in compensation payments [6].

Accident Forms were acquired from all NATA members throughout the country. This report covered 90% of all reported accidents during 1977. 60 Accidents or 2.5% of all injuries occurred by falls from the headramp to the ground. Mean number of lost days per accident was 45 days. 134 accidents or 5.0 % of all injuries was a fall from the upper level of the trailer to the ground. Mean number of lost days per accident was 29.5 days [6].

Another design problem that occurs in these trailers involves the extension of the lower loading ramps. The loading ramps are used to drive the vehicle onto the body of the trailer. Although the trailers have some hydraulic actuation in part of the ramps, the lower ramps are often manually operated. The loading ramps are loaded and raised into and out of the storage tracks which are under the trailer using one of 2 techniques:

1. Use of the winch bar to pull and push the loading skid into position
2. No tool used, driver bends or squats to position the loading skid by hand.

Although the use of the winch bar prevents excessive bending and squatting during ramp positioning, it may not eliminate the bending component on the trunk (back). There is less control of the loading skid positioning when using the winch bar. The shoulder and back are held in a more neutral position without having to raise the arm excessively. However, if the tract in which the skid rides is damaged from bumps in the road or id gravel or debris are in the track, the ramp may jam unexpectedly. This rapid stop of movement results in high torsional forces on the shoulder and lower back. When handling the loading skid without the winch bar the operator must bend at the trunk and lift the ramp to pull it out to the loading position.

These ramps have low ground clearance and frequently cause injury to the driver, primarily to their back, consistently enough to merit a redesign. With the ramps being so low to the ground, the operators loading the vehicles have to bend over to manually extend the ramps and this is where one problem lies.

Also as stated above, over time, these ramps are susceptible to a certain amount of damage due to road debris and, in the colder climates, salt damage and corrosion. This adds to the problem in jamming while extending the ramps.

To be successful, the design must satisfy several parameters or functional specifications. First, the system must be able to fully extend and retract the aluminum loading ramps, which means 2.5 m of traverse for the trailers in a typical design. The system must also be reliable and durable, because the operation must be dependable. If the device fails there is a tremendous loss of capital at stake, both in the form of time lost in delivering cars and also potential injury of the operator in failure. Due to the large loads carried by the trailers and exposure to the elements, the durability of the system is again a large factor, since the trailers must have a long-life span. Because the design is for existing trailers, it must be compatible with multiple large trailer types, from 10-14 cars. Due to this parameter, the design must function as an accessory or kit that is compatible with all typical car trailers.

The re-designed system must be safe to operate and with minimal strain on the operators. However, the design must be cost effective and easier to implement than the addition of the hydraulic actuation.

II. CURRENT TRAILER DESIGN CHARACTERISITCS

Before to load and unload cars onto the trailer, the loading ramps must be fully extended. The cars on the upper level are loaded first, and then the hydraulic cylinders are activated, raising the platform and allowing more cars to load on the bottom level of the trailer. In a manual loading ramp system, the ramps must be extended and retracted fully by an operator, usually the driver. The ramp system of an existing design is shown in the picture below.

Figure 1 Car trailer with ramps extended

In Fig. 1 the ramps are shown fully extended. The ramps are located in a channel on the undercarriage of the trailer, where they retract for storage. As shown by the Fig. 1, the ramps must be picked up and manually slid back into the channel for storage. Fig. 2 shows more clearly the close proximity of the working range of the ramps to the ground.

Figure 2: Side view of trailer with loading ramps fully extended

Fig. 2 shows the starting height of the ramp to be below knee level with respect to the average size operator seen in the figure, and the ending height is obviously the ground; therefore, the entire operation must be performed at an unstable position of the back, meaning a high risk of injury to the operator. To determine the typical dimensions of the ramps a car hauler supply company was contacted to get information on the ramps. The dimension of ramps for car trailers range in size from 150 cm to 335 cm long, in width from 38 cm to 61 cm and in thickness from 4 cm to 15 cm. The most popular sizes are 46 cm x 230 cm x 4.5 cm and 43 cm x 250 cm x 6 cm. The ramps are shown very clearly in Fig. 2.

The figure shows the starting height of the ramp to be below knee level with respect to the average size man in the picture, and the ending height is obviously the ground; therefore, the entire operation must be performed at an unstable position of the back, meaning a high risk of injury to the operator.

III. Problems with Existing System

Although there are many factors that make the current system problematic, one of the biggest causes of injury is the condition of the drivers themselves, who are typically the ones operating the ramps. Due to the nature of the job, which entails quite often long driving distances to transport the cars and thus long periods of time sitting in the same position, drivers are generally not in peak physical condition. This problem propagates when a driver sustains a back injury; not only does the extended periods of time in the seated position aggravate the injury, the worse physical condition a driver is in, the slower the injury will heal, resulting in chronic damage. Drivers are also often in their late forties and early fifties, further putting them at risk for injury.

In addition to the driver problems, the ramps and loading channel undergo damage themselves that inhibits operation. The trailers are exposed to the elements almost constantly, and dirt and grime from the road also contaminates the components, which causes extensive corrosion to the ramp channel and other parts. The low proximity of the ground also causes the trailers to bottom out, which causes severe damage to the ramp housing and other parts, and can even bend the ramps, as is seen in Fig. 3.

Figure 3: End view of ramp channel showing corrosion and damage

Since the low proximity to the ground already places the operators in a position to sustain injury, as operation becomes more difficult the likelihood injury increases also. When the ramp operation is impeded, other minor injuries such as jammed and smashed fingers and appendices often result as shown in the Figs. 4 and 5 below.

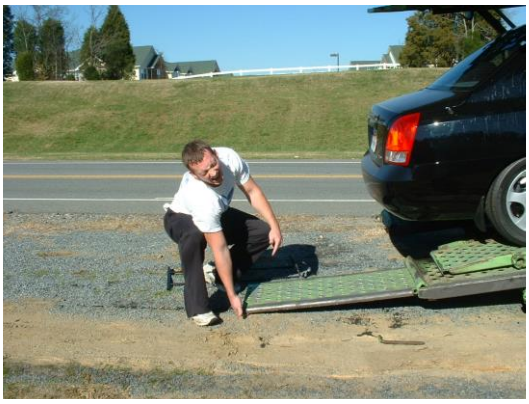

Figure 4 Fingers being smashed between ramp and ground

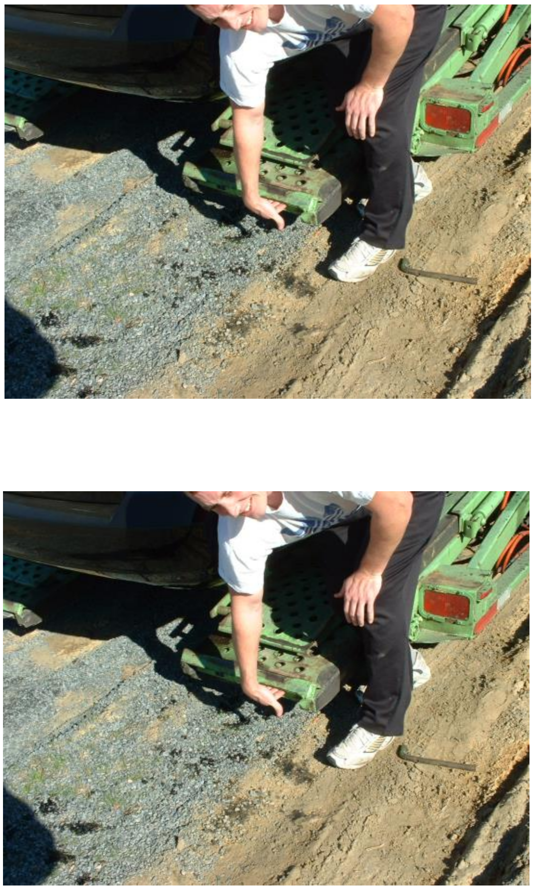

Figure 5 Fingers being smashed while retracting ramp.

IV. Existing Designs of Hydraulic Loading Ramps

A. General Overview

Since the invention of the car trailer in the 1930's, alterations and improvements have been sparse. Although there are currently some hydraulic systems for the loading ramps, they are only on the newest trailers and have many problems. There are several variations, but the most common is a single one-stage hydraulic center located between the ramps. The ramps are connected by a steel piece and extend and retract simultaneously with the cylinder activation. Such a system is seen in Fig. 6.

Figure 6 Hydraulic Loading Ramps on a Commercial Car Carrier

Another design again uses one-stage cylinders, but has them contained within the ramp channel. This system requires a hydraulic cylinder in each channel, which extends to the full length of the ramp. Such a design makes this system costly and impractical because of flexure in the long hydraulic cylinders.

B. Problems with Designs for Project Application

Both systems discussed in the previous section are at best problematic. One of the biggest problems for both is the length that the cylinder must extend. For the current application that is a minimum of 8 feet. Due to the near horizontal position of the cylinder, the cylinder sags under its own weight, making operation difficult and not only producing chatter and wear on the components, but can also result in failure. Failure of a hydraulic cylinder not only prohibits any operation of the entire trailer, but can also be very dangerous due to the high pressures involved in hydraulics. In the single cylinder design, the cylinder also lacks horizontal stability, which causes the ramps to come out of the channel and operate non-uniformly. In the in-channel design, the ramps will move at different speeds and the sagging in the cylinder causes zones of instability.

V. Biomechanical Analysis of Back Injury in Lifting

A. Significance of Problem

The problem of back injury to operators is certainly not an uncommon occupational problem. According to orthopedic research initiated by OSHA (Occupational Safety and Health Administration), research has shown that nearly two thirds of all people in the industrial world suffer from debilitating back pain at least once in their lives [7], and up to 80% of the adult population will experience some form of lower back injuries [8]. According to the same statistics, Low back pain produces the largest health-related expense in our national economies, resulting in 10 to 14 billion dollars in compensation costs and up to 100 million annual sick days in the United States alone [9]. Not only are these injuries prevalent and harmful, but they are also extremely costly. The sources for these injuries are usually improper lifting techniques and overuse [8], both of which are present in the operation of the hauler ramps.

A. Biomechanics Overview

The stresses on the back and vertebral column can be expressed using common engineering terms and models. Stiffness is defined as the "ability of vertebral column to resist applied load [10]. Counter positively; the lack of stiffness is then the inability to resist loads, which leads to instability, or movement. These loads can be described using simple elasticity and solid mechanics terminology. The vertebrae are subjected to axial compression, tension, and bending moments, not only during activity, but also at rest. These loads are amplified during lifting or other strenuous processes. The ability to resist these loads is a function of both the type of loading incurred, and the physical condition of the operator. Variations in age, posture, and also structural integrity of the vertebral bodies, joints, disks, muscles, and ligaments are all determinants in the likelihood of failure leading to injury. Figs 7-10 show the forces on the human body while performing the tasks with the deployment and return of the loading ramps during a typical car hauler loading process.

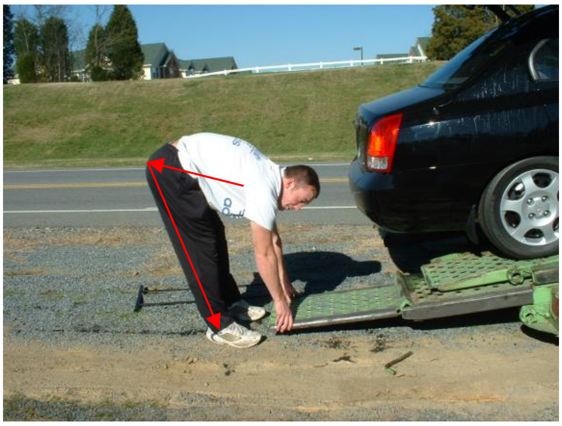

Figure 7 Torsion and Bending Moment in Lifting and Extension of the Ramp

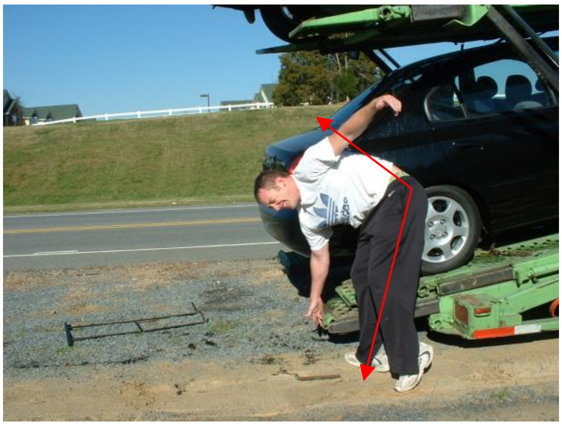

Figure 8 Torsion and Shear during Full Ramp Retraction

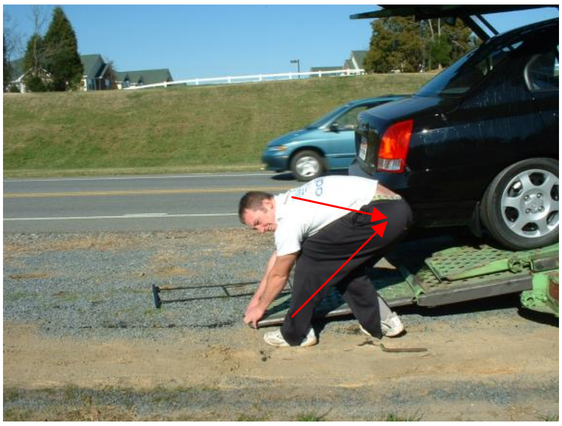

Figure 9 Axial Compression and Bending Moment during Retraction

Figure 10 Extension and Compression returning to the Standing position

B. Axial Compression

Axial compression occurs when a force is applied in the normal direction to the disks and vertebrae along the spine of the back [11]. This force acts on the intervertebral disk, which is formed by the nucleus pulposus and annulus fibrosus, placing it in compression. The annulus fibrosus is the soft tissue that surrounds the nucleus pulposus, which is a ball of fluid that is deformed by compressive force. However, when load is applied to the annulus by the endplates, the resultant pressure in the nucleus is actually greater than the applied load. After age 40, this pressure increases further as the result of the decrease in compressive strength of the bone, and a decrease in bone density. Also, intervertebral fluid from the nucleus is lost over time with excessive use and injury, so therefore, more force over less area results in much higher stresses with aging, and more susceptibility to injury. Fig. 11 illustrates the forces acting on the intervertebral disks during axial compression:

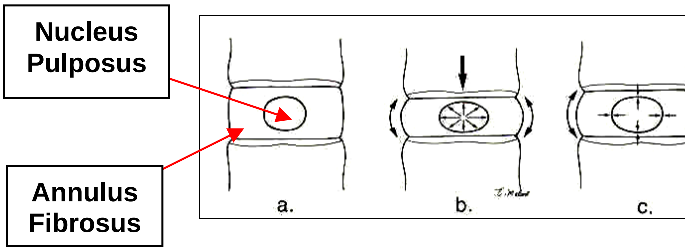

Figure 11 Intervertebral disks under axial compression

- **a.** A diagram showing nucleus and annulus between non-compressed vertebrae.
- **b.** This schematic shows the compressive loading on the nucleus which exerts pressure in all directions as it attempts to expand. This pressure results in tension on the annulus.
- **c.** Now the annulus exerts an equal and opposite force in response to the rising pressure, which under stable circumstances results in equilibrium. Fig. 11 also shows the pressure exerted from the annulus on the endplates of the vertebrae.

C. Flexion and Extension

In bending, the structures of the spine are subject to both compression and tension, depending on whether the bend is flexion (forward bending) or extension (backward bending). Not only do these forces exert stress on the anterior structures of the spine, but with sustained loads in flexion and extension, creep can also occur in the ligaments and collagen fibers, which leads to excessive movement and instability. This instability almost always results in a trickle down effect, with not only pain, but eventually, debilitating injury. Fig. 12 illustrates the mechanisms for bending and also the causes of pain and instability resulting from the excess in normal movement patterns of flexion and extension:

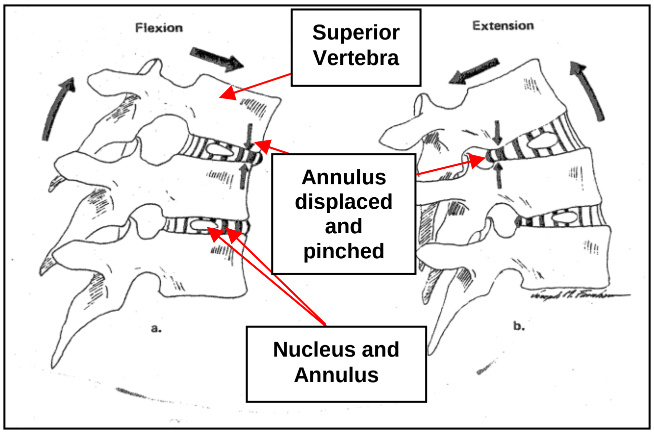

Figure 12 Flexion and Extension in Vertebrae

In flexion, the superior vertebra tilts anteriorly, compressing placing the annulus. Repeated or excessive amounts of compression cause hyperflexion, in which the vertebra is tilted beyond the normal range of motion. This excessive tilting can force the annulus to displace outward on the anterior side, causing it to be pinched between the vertebrae. This pinching motion can potentially cause compression of the nerves which is a resultant source of pain. The same is true for extension, in which hyperextension and pinching of the annulus on the posterior side can occur. These mechanisms are a leading cause for pain and injury in the lower back.

In addition to the skeletal problems that hyperextension and flexion may induce, they may also result in damage to the ligaments and musculature of the back. Figs. 13 and 14 show the same motion with respect to the ligament structure.

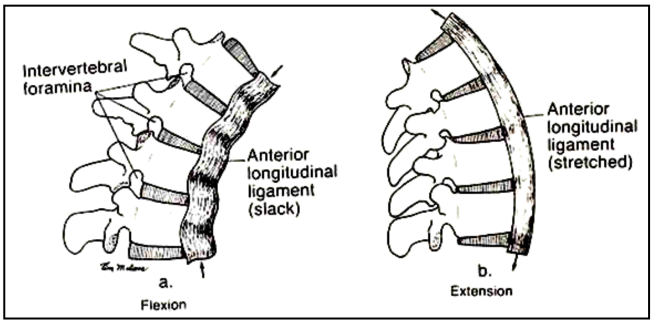

Figure 13 Anterior Longitudinal Ligament (ALL)

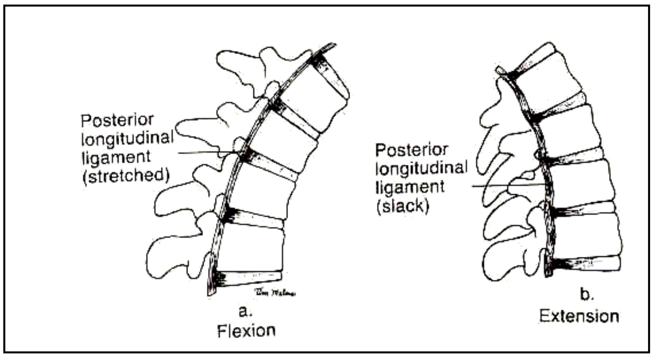

Figure 14 Posterior Longitudinal Ligament (PLL)

Figs. 13 and 14 show, forward bending induces compression in the anterior longitudinal ligament (ALL), and tension in the posterior longitudinal ligament (PLL). The opposite is also true; extension compresses the (PLL), and induces tensile stress on the (ALL). In the condition of excessive strain in which hyper movement occurs, these ligaments are subject to a sprain injury. With repeated loading cycles, creep mechanisms can also occur and stretch the ligaments beyond their elastic limit, which then creates instability due to the lack of elasticity and recoil. This condition of inelasticity is referred to as hyper-mobility; when there is an increase or excess in movement at a joint, (which will also be discussed with respect to lifting.) Although it is more common in ligaments, this problematic mobility is also prevalent in muscles as well. Often hypermobility is the result of inflexibility or hypomobility in a synchronous joint, meaning that the lack of ability to move in one joint creates an excessive movement in a related joint [12]. In reaction to hypermobility in which the muscles are overly excited, the body induces muscle spasms, commonly referred to as back spasms, which not only further decreases the ability to function, but causes tremendous pain. Problems of the nature are common to the spine, and in the lower back predominantly in the sacroiliac joint.

To induce forward bending, the flexor muscles contracts, placing the extensors in tension and the (ALL) will also be stretched to support the lumbar vertebrae and disks. In this motion, the lumbar tilts in coordination with the anterior tilting of the pelvis, referred to as the Lumbar Pelvic Rhythm. With the onset of lifting, more bending occurs which increases the stress-tension relationship, which serves to amplify the tensile and compressive stresses in the components. This motion can be modeled as a simple spring, when bent the spring is elongated, as bending continues the elongation increases until the point where the yield stress is reached and permanent damage occurs. This excessive stress results in instability and permanent injury. Fig. 15 illustrates the forward bending motion of the body.

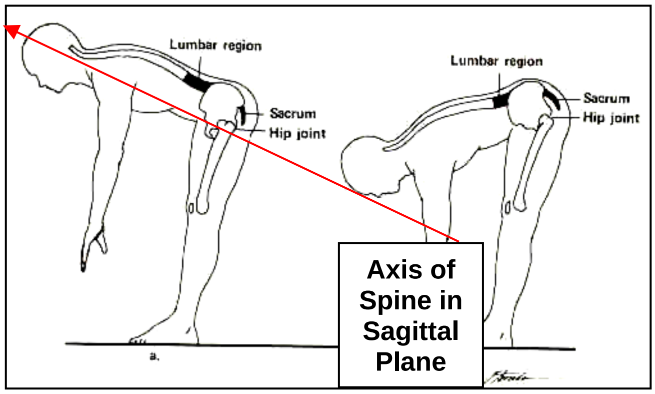

Figure 15 Forward Bending Motion

As the Fig. 15 shows, the greatest amount of bending occurs in the Lumbar and Sacral regions of the back, primarily between L-4 and S-1, which means Lumbar vertebrae 4 and 5, and Sacral Vertebrae 1. As shown, the bending occurs in the sagittal plane of the body, which is the axis that divides the body into two symmetrical halves between the eyes. Any deviation from the sagittal plane, such as lifting objects from the side or turning creates a torque and subsequent shear force on the vertebrae.

Problems with this motion are largely specific to the individual and related to the previous hyper- and hypo-mobility problems naturally present. Restriction (Hypomobility) in one segment of the lumbar or sacral region will result in excessive mobility of the unrestricted segment. For example, a person with restriction in the L-5 vertebrae will experience hypermobility in the sacral region, which causes anterior or posterior rotation at the sacroiliac joint, which can stretch ligaments beyond elastic limit, and cause frequent pain and injury. This condition of mobility and subsequent injury can be triggered by excessive, endurance loading activities such as lifting. Often, hyper- and hypomobility are present from on either side of the pelvis. This excess mobility causes uneven levels in the pelvic region, which again puts stress and strain on the ligaments and causes pain. Although only a few possibilities are mentioned, there are many more sources of injury and pain in the lumbar and sacral regions, leading to further defects such as spondolysis (a fracture of the pars interarticularis of the L-4 or L-5 vertebrae.)

D. Lifting

Although lifting is a significant catalyst in the onset of injury, these injuries are to a large degree preventable with proper lifting techniques and guidelines. As mentioned previously, when lifting is induced after forward bending, such as the motion of bending over and extending the ramps, the posterior muscles and ligaments are flexed. As the spring model shows, the bending induces tension, which is increased when the back tries to lift. Not only is there a significantly smaller mechanical advantage (small ligaments and muscles are trying to overcome massive moments produced by length of torso and arms combined); the pre flexed condition reduces the ability to lift. The spring (back) has a finite yield stress that is reached much sooner if already pre-stressed, resulting in smaller load able to be lifted and a dramatic increase in damage (injury). Therefore, all effort should be made to avoid lifting in the pre-flexed condition, shown in Figure 15. Similarly, stable positions, positions where equilibrium is reached between members, should always be maintained in lifting.

The distance of the load from the body determines the moment produced by lifting. The farther the load from the body, the larger the gravitational moment produced on the vertebral column. In lifting, the load should be placed as near to the body as possible, if necessary by means of a lever or other prosthesis, such as the “orthopedic handle.”

Much research has been done to determine the optimal speed of lifting. When lifting is performed slowly, the weight must be stabilized and supported by all of the skeletomuscular components (muscles, ligaments, and bones) throughout the lift. For this reason, only 25% of a similar maximum load lifted at high speed can be lifted [10]. The constant force of slow lifting induces creep mechanisms on the ligaments and muscles, which tears the collagen fibers and causes irreparable injury.

E. Other Contributing Factors to Injury

As mentioned before with axial compression, the body’s structural components change for the worse over time. Due to the extensive reduction of integrity in the components, the spine is unable to endure stresses that previously were not dangerous, resulting in an increase in the likelihood of injury over time. Aging also changes the entire structure of the disks, which due to the close correlation of components, compounds into a larger problem. With age the average intervertebral fluid content of the disk decreases, this not only increases pressure in the nucleus, but also decreases the distance between the vertebrae, meaning that much smaller tilting motions can now displace and pinch the annulus. With this reduction of fluid, there is more contact and therefore more friction and subsequent wear on the disks and vertebrae with motion. Also, with the reduction in height, the ligaments are now slack which increases hypermobility. The physical fitness of the individual is again a large factor in vulnerability to injury. Smoking and excessive weight, both common characteristics of truck drivers, are detrimental to the back. Smoking damages the structural integrity of the vertebrae, ligaments, and muscles, and excessive weight puts more nominal stress on the back.

F. Injury Investigation Conclusion

The rigors of the bending and lifting in pre-flexed condition with a displaced load, coupled with the sustained stress of long hours in the seated position places drivers at risk for injury. It has been substantiated by research that many back problems are a result of “mechanical stresses produced by static postures in the forward stooping or sitting positions and the repeated lifting of heavy loads [10]. These injuries are preventable, however, and can be reduced by proper lifting techniques and better physical condition.

Currently, all forms of loading on the back are present in the manual ramp extension process.

In further analysis of the ramp extension process, injuries to the fingers and toes are possible. In extension, the ramps must be pulled by the fingers, which can be smashed easily on the ground at full extension. In retraction, the fingers are subject to being pinched by the ramp against the channel. In response to all of these possible risks in operation of the ramps, with an effective design of extension and retraction, all sources of injury could be reduced or eliminated.

VI. Design Alternatives

All of the proposed “quick fixes” or improvements are feasible and could enhance operation of the existing system, but are not solutions to the design problem. The following design alternatives are investigated to solve or lessen the problem. As stated before, these designs need to effectively extend and retract the lower loading ramps with minimal or, if possible, no strain or injury to the driver. The design must also be compatible to use on an existing large car hauler (10-12 cars) and have minimal cost to increase practicality of its use. With this in mind, the following five design alternatives were investigated:

- Telescoping Hydraulic Cylinders
- Single Hydraulic Cylinder with Stabilizer
- Orthopedic Handle
- Hydraulic Cylinder with Sprocket
- Hydraulic Lever System

VII. Selection of Design

After considering each alternative, it was felt that the design that best completed the design problem stated earlier is the “Orthopedic Handle”. The reason for this conclusion is as follows. First of all, it was the most cost-efficient design. We estimated the value of an older model trailer to be around $5,000 to $20,000, and then considered the cost of a hydraulic system to be installed to the existing system for the ramps would meet or exceed this value of the overall trailer. This design is also easily adapted to the existing trailer design. The only modification that would need to be done to the trailer is maybe a clamp or hook to attach the “Orthopedic Handle” to the trailer while in travel. This will also minimize the chance of catastrophic failure that might exist with some of the other designs that needed to splice into the hydraulic system of the trailer. With the other designs, there would be increased pressure on the hydraulic lines which could lead to failure and/or danger to the operator. Installation Hazards and complications would also exist with the other designs. The safety of this design is also a key point, as the other designs introduce more moving parts which, in turn, create multiple pinch points for the operator or spectator.

VIII. Development and Testing of Prototype

In developing a prototype of the “Orthopedic Handle” we came up with some dimensions that we felt suitable for an average truck driver, and are adaptable to different size ramps and trailers. In testing the prototype in a real world situation, it was found that it succeeded in satisfying all the design criteria. As presented in the following figures, it successfully extended and retracted the ramp with ease. The pictures also show how the design transfers the load from the low height of the trailer up to waist height, which in turn minimizes or eliminates any bending while applying a load. As discussed earlier, this is the proper positioning that should be practiced in load application.

1. ***Extension***

   Fig. 16 shows the successful deployment of the ramps without injury and low stress levels to the operator as the body is in a much more neutral position.

Figure 16 Successful Deployment of the Ramps

Figure 17 Safe Performance of Complete Operation

2. Retraction

In testing the prototype, it was also found that it was applicable to different designs of ramps. Also in testing, it was found that a number of modifications could be done to the design to improve it. First, it was found it necessary to shorten the length of the hook at the end; with the length of the prototype hook, there was a limited range of how far the device could be drawn back while extending the ramps, due to the narrow thickness of the ramps. The design was also simplified the design by decreasing the number of hooks to from two to one. This enabled the handle to be more applicable to a wider variety of ramps as the spacing of the holes changes between ramps. The single leg design is also better for retracting the ramps, as it was found in testing, that a trailer that is full of cars, it was sometimes necessary to stand alongside the rear of the trailer to fully retract the ramp without hitting a loaded car with the end of the handle. In addition to this, as it was tested with two different heights of operators, it was also found that it would be in best interest if the design was made adjustable to different lengths. The final design will extend from 3 feet long to 4 feet long with a simple push button adjuster similar to that of a medical crutch. Also, to make the design light weight, aluminum was used to manufacture the final design. A detailed picture with the dimensions of our final design is shown in Fig. 18.

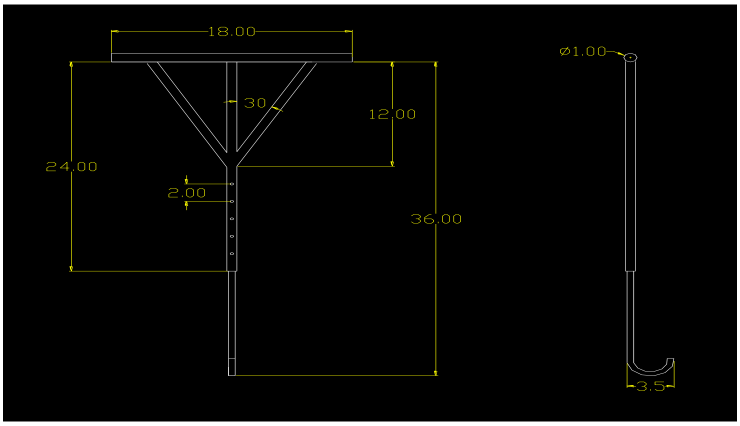

Figure 18 **Dimensional** Drawing of Final Design

IX. Conclusion

Based on the initial studies, three design were selected to seriously consider: the Orthopedic Handle, the Stabilized Cylinder, and the Lever 2002 designs (previously considered mechanical design). Then, after coordinating with the project advisor, as well as evaluating each design according to the design parameters and functional specifications the final decision was made that the Orthopedic Handle being the best design. In developing and testing this design it was found it to exceed our expectations with minor adjustments. The Orthopedic Handle well satisfies the design problem that was set out to accomplish at the beginning of project. Even more impressive, the project was budgeted between $1500 and $3000 for material costs to make and test a working prototype. It was able to manufacture a working prototype from scrap materials for a total cost of $0. In most design criteria evaluation methods, such as decision and Pugh matrices, cost is usually the largest parameter. By this measure alone the design is a dramatic success, and the implementation costs are exponentially less than any other alternative, making this a superb design.

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