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Development of Next Generation Column Guard for Storage Rack Protection

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Abstract:

This paper reports on a multi-year engineering design project involving undergraduate engineering students. The project involves the design, development, and prototyping of a next generation pallet rack column guard. The guard allows for the engagement and protection of a storage rack upright (column) from an impact force by an external object such as a forklift. The guard protects the storage rack by absorbing and damping the resulting impact force. The guard is constructed from an injection-molded thermoset elastomer. Elastomers can store and release more potential energy per unit mass (or volume) than steel and plastic guards. This translates to greater energy absorption which will help preserve the structural integrity of a rack upon impact thus protecting the general public in retail (big-box) stores and warehouses. The main objective of the project is for the student to experience the open-ended, iterative nature of the design process. Students also perform impact and stiffness testing on numerous prototyped designs. These designs are benchmarked against current designs and optimized for enhanced performance. Finally, students are engaged in production, marketing and web-site development after the product is finalized. The design project supports ABET Student Outcome 5 and 7: Ability to function effectively on a team, and Ability to acquire new knowledge.

1. Introduction:

This paper reports on a multi-year, industry-sponsored engineering design project involving the design and development of a column guard used to protect storage racks from forklift impacts. The project was used to support four separate undergraduate senior projects spanning a time-period of four years and involving 16 mechanical engineering students. This paper details some of the work completed by the senior-project groups for the first two years. The end-result is a patented injection-molded elastomeric column protector currently in production and used world-wide to protect the structural integrity of storage racks. The final group (year 4) continues to work on refinement and development of a next-generation extruded column guard for enhanced performance and lower cost. Note, due to the size and extent of the work involved, this paper will only provide detail for years 1 and 2. Another separate paper will detail results for years 3 and 4.

The author has published significantly in the field of engineering design and capstone projects[1-8]. Some recent publications include:

a. Reference [1] presents the design of a low-cost 3D printer using off-the-shelf components. The printer is constructed and then used as a demo for a high school STEM outreach project.

b. Reference [2] illustrates how design projects can be used to foster self-directed learning (SDL). This paper details how various course design projects are used to help students gain knowledge of high-level engineering software programs through SDL while satisfying ABET outcome 7 to "acquire new knowledge."

c. References [3 – 6] detail various senior capstone projects whereby groups of students are partnered with industry and faculty to solve large, complex engineering problems.

d. Reference [7-8] describes the design of a multi-stage, parallel shaft, gearbox used as a speed-reducer. The main objective of the project is for the student to experience the open-ended, iterative nature of the design process. This paper further discusses a student-led honors project involving not only the design but also the construction of a low-cost gearbox demonstration unit. The gearbox demonstration unit is designed and built to give future students in the machine design course a visual, hands-on way to understand and internalize the working of gear trains as either speed reducers or torque reducers.

2. Basic Project Overview:

Pallet racks (Figure 1.A.) used in warehouses and retail (big-box) stores are subject to damage from the everyday uses that commonly occur in busy warehouse environments. Damaged columns (Figure 1.B.) pose a risk to the public due to potential for collapse of the rack. Damaged rack must also be replaced which requires a portion of the retail space to be closed-off for an extended period while maintenance performs the necessary repair. A column guard (Figure 1. C and D) will be designed to protect the columns at the base where they are most susceptible to damage from frontal and side impacts from forklifts and other impacts. There is a wide range of products designed to help protect pallet rack columns from damage. These products include steel reinforced columns, slat-back or offset frames, floor-mounted steel guards, bumpers, barriers and aftermarket attachable guards. Specific goals of the proposed column guard provided to the students by the industry-sponsor include:

- Must be removable and replaceable with toolless installation (i.e. no anchors or bolts like steel aftermarket guards)
- Minimum length (protection) of 12 inches and must accommodate 70 – 80% of all rack geometries on the market
- Must outperform existing thermoplastic guards on the market while meeting a target price
- Must be durable and withstand multiple frontal and side impacts while protecting against costly column and frame damage

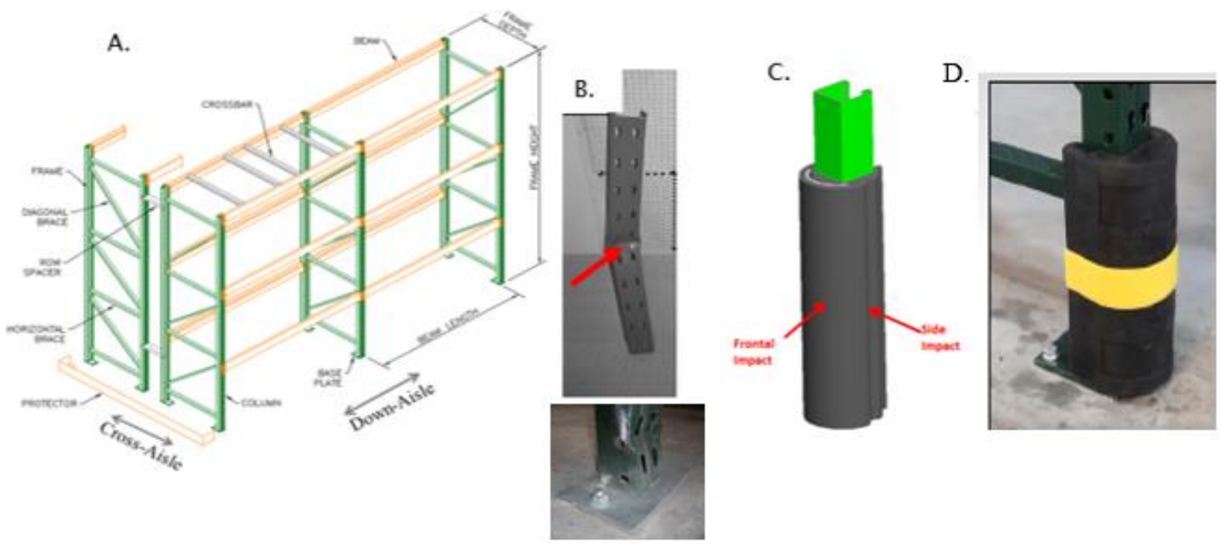


Figure 1: *A*. Typical Pallet-type Steel Storage Rack Configuration (*RidgURak [9]*), *B*. Damaged column from forklift impact, *C*. elastomer column guard offers front and side impact protection, *D*. Final production injection-moldable column guard.

3. Year One – Benchmark Testing:

A group of four mechanical engineering students are assigned to the first, year one, project. Students met with the industrial sponsor [9] and constructed a list of project goals. The emphasis of year one is to establish a performance benchmark for current rack protection technology. Specific goals include:

a. Perform a detailed marketing and patent search to determine the current 'state of the art' in terms of storage rack protection. Procure all industry-leading competitor guards for benchmark testing and evaluation (see Figure 2.A.).
b. Storage rack market survey to determine the various column configurations and geometries. Based on this study, students determined that 80% of all racks in conventional warehouse and 'big-box' stores have a width of 3 inch and depths of either 1 5/8, 2 ¼, 2 ¾, and 3 inches (Figure 2.B.).
c. Design and build custom impact tester for testing columns found in a. Record impact force (g's) for competitor guards. Note, the impact tester was built to FEM 10.2.02 standards [10] with a failure (column replacement) criteria of > 5/16 inch (8mm) permanent rack deformation. The potential energy of the impact tester is adjustable via height and suspended weight with a maximum equivalency of a 5,000 lb. forklift impacting a column at 3 mph (the condition used to characterize guard performance). Details of the impact tester are shown in Figure 3.
d. Identify the top-performing column guards and measure static and dynamic stiffness. This data is used to establish stiffness and deformation criteria for new guard. All stiffness tests performed on a MTS 810 load frame (Figure 4).

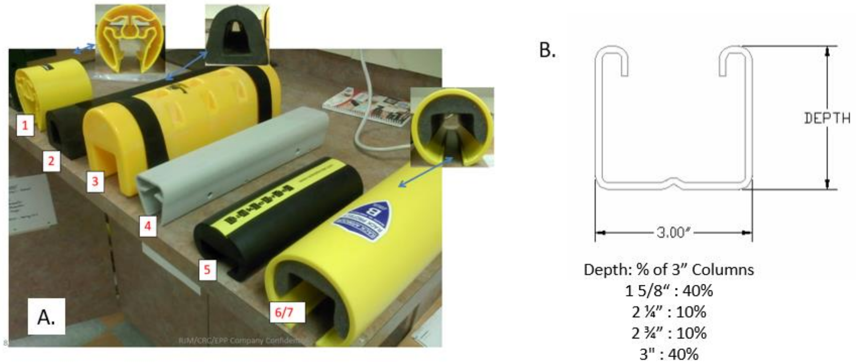


Figure 2: Results of 'state of the art' marketing study. *A.* Current leading column guards, *B.* Standard roll-formed rack cross-section accounts for approximately 80% of all storage racks for retail and warehouse.

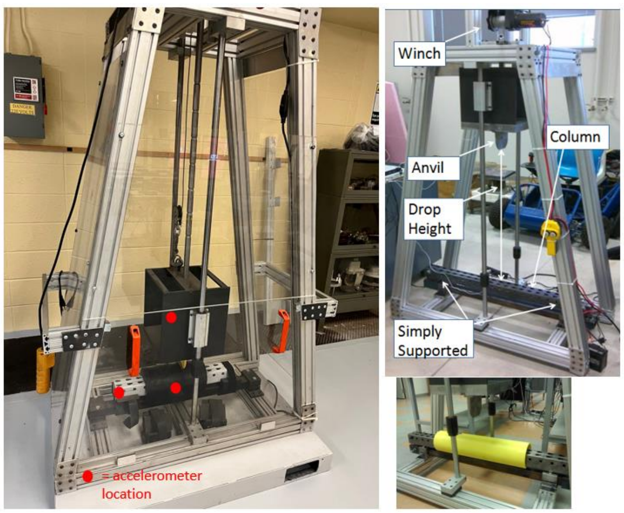


Figure 3: Impact tester designed to FEM 10.2.02 [10] to simulate forklift impact. Students designed and built the impact tester for benchmark testing to determine front and side impact protection of various column guards.

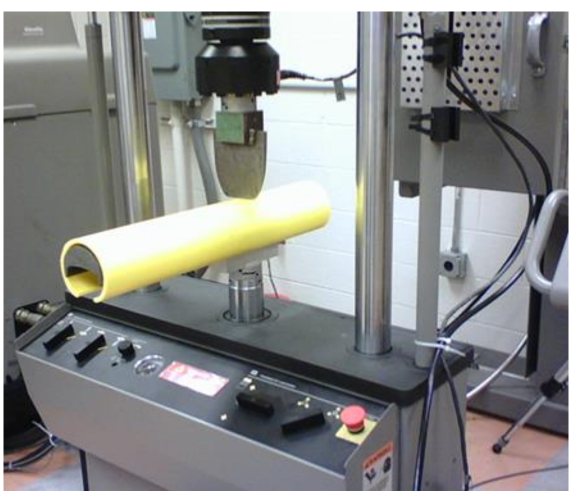


Figure 4: Stiffness testing to characterize static and dynamic properties of various column guards.

The above benchmark testing provided students with the necessary set of column guard parameters for optimal performance. Main conclusions from impact study:

- Elastomer guards seem to outperform plastic guards due to the materials ability to absorb and dissipate energy.
- Elastomer guards resulted in lower peak acceleration level at column.
- Column will strengthen and sustain more impacts with addition of a metal insert which adds to column section modulus and stiffness.

Based on these conclusions, numerous prototype guards were fabricated using standard 'sheets' of elastomer [Figure 5.A.]. Durometer (stiffness), damping, elastomer type, thickness and geometry were varied as part of a design of experiments. Each prototype guard was impact tested to measure performance. Various impact simulations were also performed in ANSYS [11] to investigate the relationship between column guard stiffness and resulting rack stress [Figure 5.B].

Figure 5: *A*. Fabricated prototype guards for evaluation, *B*. Impact simulations performed in ANSYS to validate testing.

4. Year Two – Development of RamGUARD™

Information gathered in the year one study was used to design and develop the RamGUARD™. The RamGUARD™ [14] is a patented injection-molded column guard currently in production and distributed world-wide by RidgURak [9]. Multiple column guard designs were created by the students using CAD [11]. Some of these designs are shown in Figure 6.

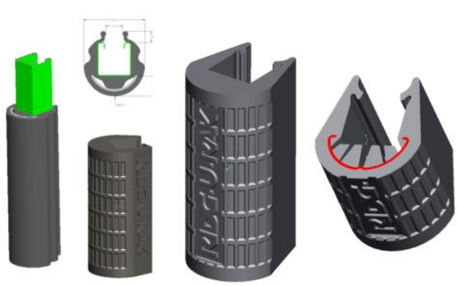


Figure 6: Various column guard designs that meet requirements defined in year one study.

The final RamGUARD™ design is shown in Figure 7. The design includes an over-molded metal shim which contributes to column strength and stiffness. A waffle pattern is molded on the inside surface as shown. This waffle pattern results in a reduction of stiffness in the inside area, so impact force is redistributed to the outside corners of the column – the strongest area of the column. The RamGUARD™ contains many features which are detailed in the patent [13].

Figure 7: Final column guard design. *A.* Injection-molded RamGUARD, *B.* Steel reinforcement column is over-molded into the rubber to increase column strength, *C.* A waffle pattern is molded into the inside surface to redistribute impact forces to corner of column.

The material selected was EPDM elastomer. EPDM has excellent environmental properties (resistance to sunlight, heat and ozone). Elastomer was chosen since these materials can store and release more potential energy per unit volume (or unit mass) than other materials such as thermoplastics. This is shown in Figure 8.

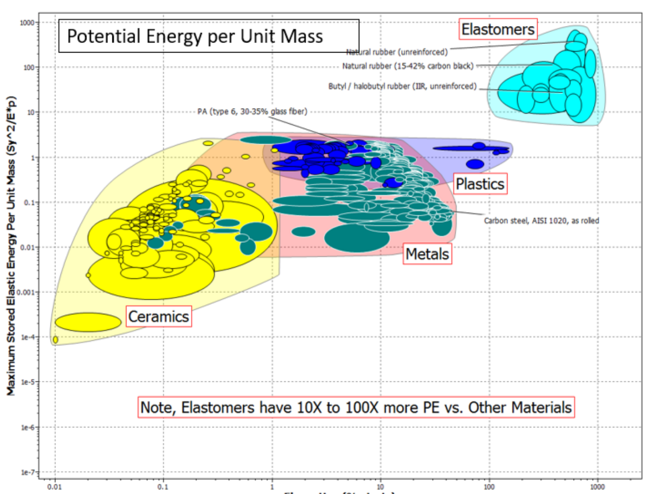


Figure 8: Elastomer was selected for the RamGUARD™ material due to its ability to store and release more potential energy per unit volume (or mass) than other materials such as thermoplastics.

The RamGuard™ was tested extensively. Impact testing was performed for frontal and 45-degree impacts (Figure 9). Results showed reductions in peak acceleration of peak impact acceleration from 700 g (no guard) to 30 g with guard. Additionally, no visible damage to the column (or guard) was evident after 20 impacts. Conversely, columns tested without the column protector showed damage after a single impact and exceeded the rack replacement criteria [10] (deformation > 5/16") after 4 impacts.

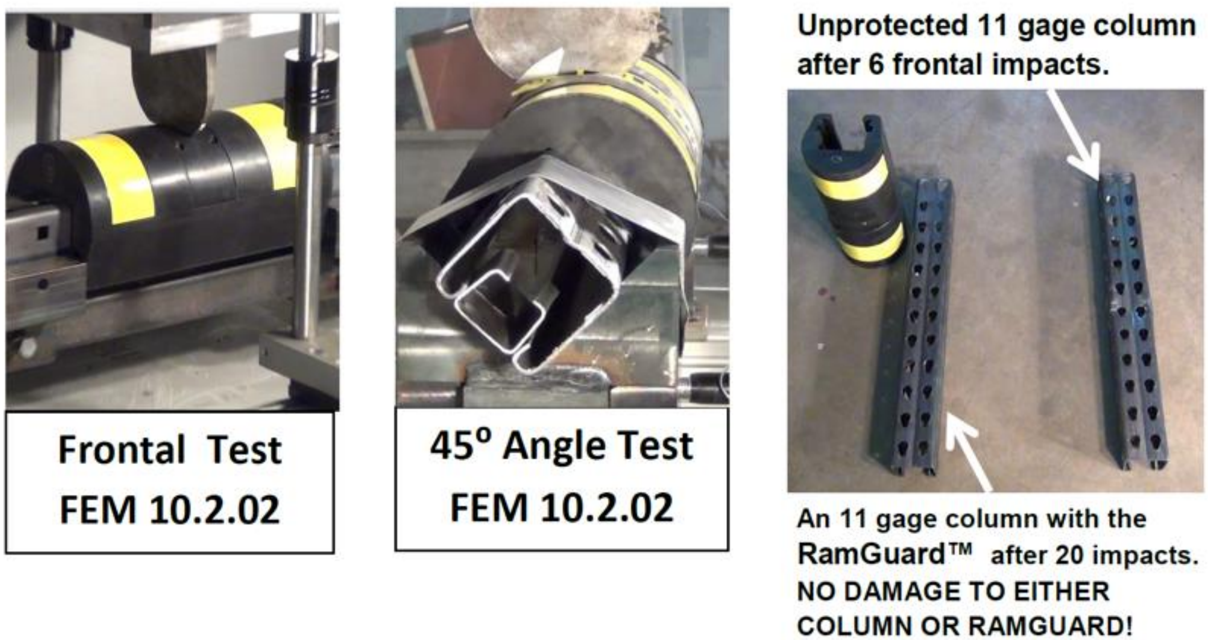
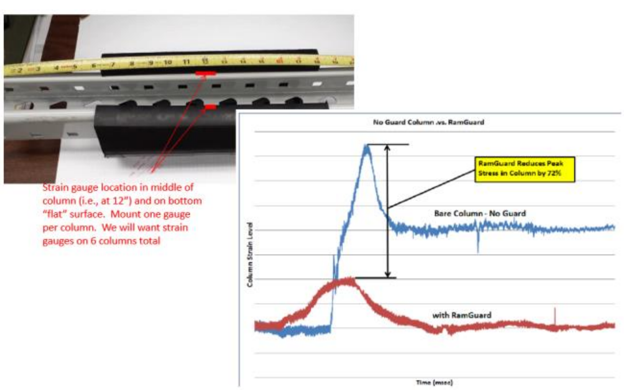


Figure 9: Impact testing was performed for frontal and 45-degree impacts. Impact testing showed reduction in peak acceleration from 700 g to 30 g with guard. Column showed no visible damage after 20 impacts.

Further impact testing was performed with strain gauges installed on the bottom surface of the column (Figure 10). Strain gauge measurement provide a better indication of structural damage. Testing shows installation of the RamGUARD™ provides a 72% reduction in peak stress upon impact thus protecting the structural integrity of the rack (Figure 10).



Upon completion of the year two project, students provided the industry-sponsor with a detailed report. Test results from this report were used to develop a website for the product [14].

5. Conclusions:

Industry-sponsored senior design projects (capstone projects) have been successfully integrated into the mechanical engineering curriculum. This paper discusses a four-year project involving 16 students. Details are provided for year one and two. Major accomplishments for year one included thorough research of competitor guards and rack configureations, complete design and build of an impact tester to material handling specifications, complete benchmark testing which included both impact and stiffness. Based on these results, prototype guards were fabricated and tested and an analytical model was created to simulate impact. Year two included the design and testing of an injection molded guard currently sold world-wide. The project exposed students to many facets of engineering design while giving them practical industry and business experience.

The design project is extremely valuable in teaching the importance of team project organization and timing, as well as product design and development, tolerancing, manufacturing techniques, testing and marketing. Finally, the design project supported the ABET Student Outcome 5 and 7: Ability to function effectively on a team, and Ability to acquire new knowledge.

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