CRASHWORTHINESS: NUMERICAL SIMULATION OF VEHILCE-STEEL POLE CRASH

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ABSTRACT

The objective of this paper is to generate research information to enhance energy absorption characteristics in transportation infrastructures involved in vehicle crash accidents. A finite-element computer model, using the available LS-DYNA software, was developed to simulate crashes of a vehicle and a traffic light steel pole in frontal impact. The finite-element vehicle model was based on a 1991, 4-door, Ford Taurus. The steel pole was modeled using shell elements to capture the three-dimensional effect of the structure. Four configurations of steel pole supports were examined. The first support type was the typical steel base currently used over concrete foundation, with anchor bolts as specified by the Canadian Highway Bridge Design Code of 2000. The second support type was similar to the first one but with stressed springs between the nuts, over and under the steel base plate. In the third case, rubber-bearing pads were utilized between the base plate and the concrete foundation. In the fourth case, the steel pole was embedded into the soil with a certain embedding length (no concrete foundation is used). The structural response focused on energy absorption as well as the deformation of the steel pole. The fourth system of steel pole supports was proved to be strong enough to offer protection during minor impacts and under service loading, and to remain flexible enough to avoid influencing vehicle occupants, thus reducing fatalities and injuries resulting from the crash.

INTRODUCTION

In North America, different types of collisions of vehicles are recorded each year, resulting in thousands of injuries and fatalities. The severity of these collisions depends on the aggressiveness and incompatibility in vehicle-to-vehicle, vehicle-to-pole, vehicle-to-curbs, and vehicle-to-guardrail collisions. Finite element models of vehicles have been increasingly used in preliminary design analysis, component design, and vehicle crashworthiness evaluation, as well as roadside hardware design. Road narrow objects (poles, U-channel sign supports, etc) are a major cause of severe injury in highway crashes. The crash event is a severe and complicated phenomenon due to the complex interactions between structural and internal behaviour. Crashed structures usually experience buckling deformation, high strain rate effects, fractures, and rapid structural unloading. This leads to highly transient response arising from non-linear stiffness and viscous characteristics of the crushed materials. One of the most important engineering parameters that engineers employ in crashworthiness is the energy absorption. This energy is used as a quantified measure to assure that the high impacts are sustained and absorbed by the structure. Therefore, the objective in crashworthiness is to build a structure on which material properties and geometrical shapes can absorb energy so that the safety regulations are achieved and more importantly the safety of the passengers is maintained. In the recent years, nonlinear explicit FE codes have advanced significantly the computer modeling and simulation of automobile crashes. This capability allows the application of the software to model and analyze the performance of the roadside objects in crashes. Among the most advanced and widely used codes, finite element simulation using explicit code such as LS-DYNA is widely used today for modeling crash problems.

The objective of this paper was to examine the energy absorption characteristics of vehicle-steel pole crash. Different structural configurations of pole supports were utilized in the finite-element modeling. Recommendations to enhance occupant safety measures were drawn.

Steel Pole Design

Straight round area lighting poles are offered in lengths from 2.5 to 12m. These standard poles accept a wide range of lighting configurations. The pole shaft is usually fabricated from hot rolled commercial quality carbon steel. The Canadian Highway Bridge Design Code (CHBDC, 2000) states that poles are to be designed to the minimum yield strength of the material with an adequate factor of safety and will withstand the dead loads of the structure as well as the specified wind loads. Standard finishes include hot-dipped galvanization, prime coat, and finish coat, both of which are available in powder or paint. The base plate is usually fabricated from structural quality weldable hot rolled carbon steel. Anchor Bolts are fabricated from hot rolled carbon steel bars with high yield strength. The threaded end is galvanized a minimum of 300 mm and each bolt is furnished with two flat washers and two hex nuts.

An increasing number of utilities are installing metal poles due to the many advantages of the metal poles over wood or concrete poles. A typical 10.4-m height steel pole (Figure 1) is used in this study. Different configurations of pole supports were utilized in this study. The first support type, Figure 2.a, was the typical steel base currently used, with four anchor bolts embedded in a concrete foundation, as specified by the Canadian Highway Bridge Design Code of 2000. The second support type, Figure 2.b, was similar to the first one but with stressed springs between the nuts, over and under the steel base plate. In the third case, bearing rubber pads were utilized between the base plate and the concrete foundation, Figure 2.c. In the fourth case, the steel pole was embedded 1.75 m into the soil (no concrete foundation is used), Figure 2.d. The properties of soil materials considered in this study were: 200 N/mm^2 for shear modulus and 2000 kg/m^{3}for density of soil.

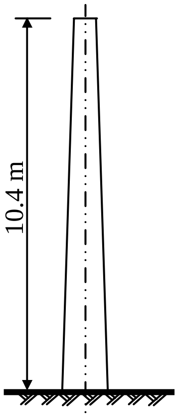


Figure 1. Steel pole

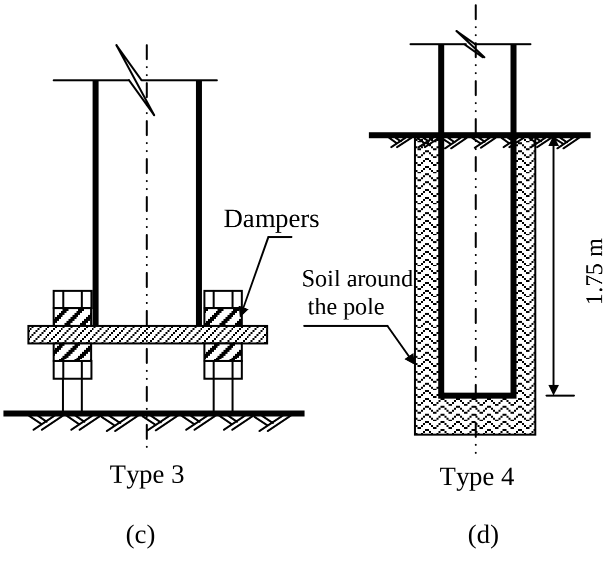


Figure 2. Configurations of Steel Pole Supports

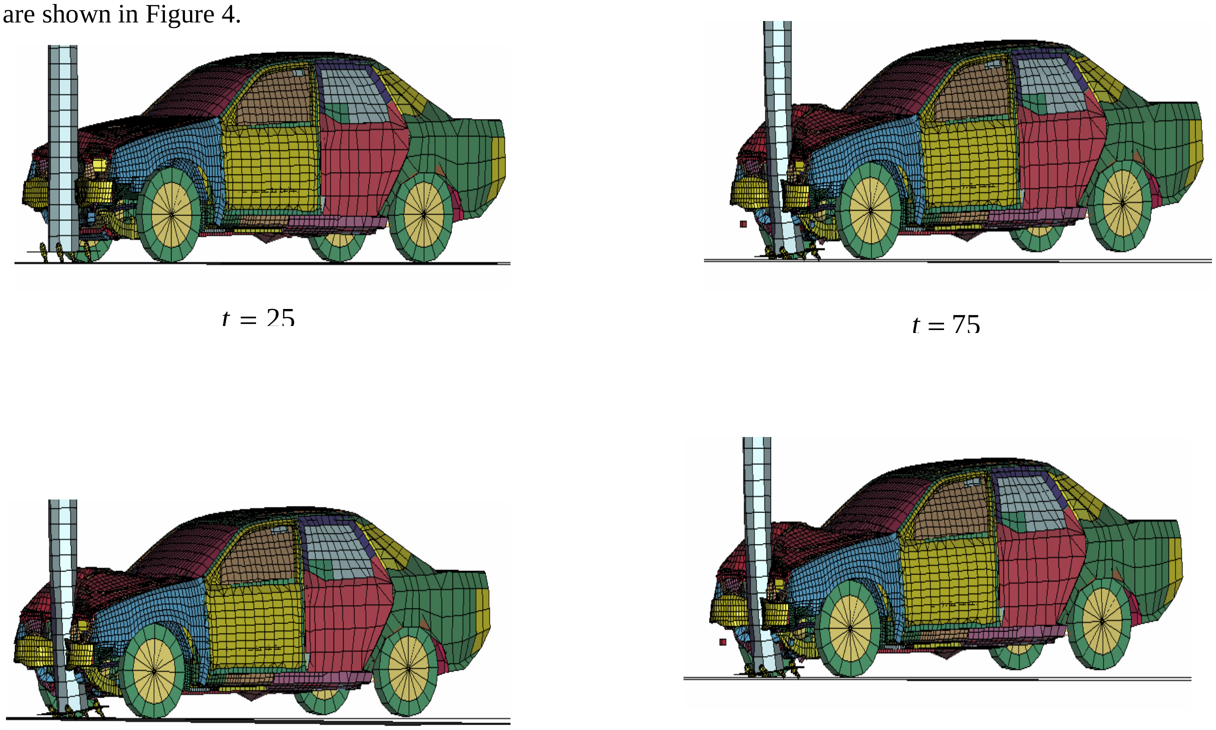
APPROACH

The steel pole was modeled using shell elements to capture the three-dimensional effect of the structure. Due to its computational efficiency, the Belytschko-Lin-Tsay shell element was implemented in the modeling. Such a shell element is based on a combined co-rotational and velocity strain formulation. Also, the same element was implemented to model the steel base. Eight-node solid elements were implemented to model the anchors and the anchor's head. In the first type of pole supports, the bottom nodal points of the pole were assumed fixed to the square steel base plate which is fixed to the ground using four dowel bars. In the second type of supports, springs, with 50 N/mm spring coefficient, were utilized. In the third support type, dampers were considered, with a damping coefficient of 10 N.s/mm. In the last support type, the pole was embedded over a length of 1.75 m into a cohesive soil that was represented by dampers as well as lateral and vertical springs.

A finite-element model for a midsize sedan vehicle has been used in a frontal impact (http://www.ncac.gwu.edu/archives/model/, 2002). This vehicle model is based on a 1991 Ford Taurus 4-door and has been already been validated for frontal impact scenario at impact velocity of 60 km/hr. The major characteristics of the complete FE vehicle model can be identified as follows: (1) 28182 shell elements, 303 beam elements and 349 solid elements; (2) 141 material cards, defining the material models employed, including steel, rubber, honeycomb, and glass; (3) Rigid (stone) wall for representing the ground; (4) automatic single surface contact from A-pillar to bumper; (5) tied nodes to surface contact between the column and the plate; (6) automatic nodes to surface contact between the bumper and the column; (7) conventional, spot weld, and rigid body nodal constraints; and (8) discrete springs, and discrete masses. The front-end components from bumper to A–pillar were modeled with a fine mesh, while the rear half of the vehicle had a fairly coarse mesh density. Components like bumper, front rails, upper load path beams, radiator, engine cradle, etc., were modeled to capture all significant geometric imperfections such as holes, beads and crush initiators which plays a vital role in overall crash characteristics of a vehicle.

DISCUSSION OF RESULTS

The finite-element simulation was performed for 100 ms using the nonlinear FE code LS-DYNA. The vehicle model was given initial velocity of 60 km/hr to impact the pole in frontal impact scenario. Figure 3 shows deformations of both the vehicle and the pole at different time increments. While the pole's deformed shapes for support types 1 and 4 are shown in Figure 4.



$t = 25$

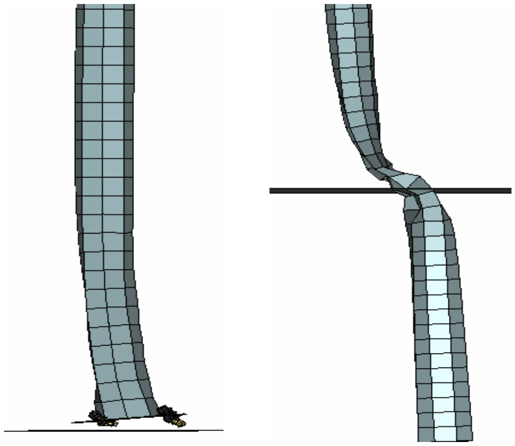
$t = 75$

$t = 50$

$t = 100$

Figure 3. Deformed shape of the vehicle and steel pole at different time increments

(time in ms)



Type (1) Type (4)

Figure 4: Pole Deformation for support types 1 and 4

All types of pole supports were impacted under the same conditions. At 7 ms, it was observed the anchor bolts utilized in the first support type fractured at the ground level, shearing the steel base plate away from the ground in the same direction of vehicle motion. Then, the pole was laid on the vehicle at higher time increment. In the second support type, where the springs were used between the bolts and the base plate, the base plate also fractured and sheared away from the ground. Similar behavior was observed in case of the third support type. However, in the fourth support type, where the steel pole was embedded in the soil, the steel pole was observed to be highly deformed and did not fall down.

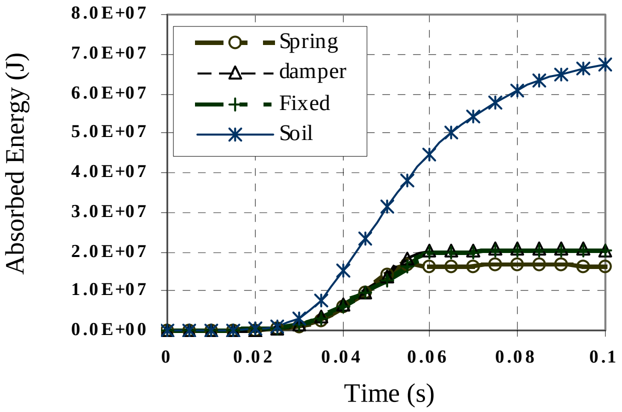


Figure 5. Absorbed Energies by different support types of the steel pole

Figure 5 shows the change of the absorbed energy per time for all the support types considered in this study. The total absorbed energy is the sum of the absorbed energy in both the vehicle and the pole. It can be observed that the first three support types provide almost the same absorbed energy. However, the pole embedded in the soil absorbed much more energy so that the amount absorbed by the vehicle is considered to be much less than that for the first three support types. This may be attributed to the high deformation occurred in the pole as a result of the impact.

SUMMARY OF CONCLUSIONS

Embedding steel pole in the soil rather than using the conventional fixed steel base over concrete foundation is proved to be favorable in absorbing the energy resulting from vehicle-steel pole crash. This definitely assists in reducing the fatalities and injuries occurred in car accidents. Further research on crashworthiness of vehicle-steel pole impact is required to reach a structural design criteria for steel poles subjected to vehicle impact.

ACKNOWLEDGEMENTS

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