
Fadi Tahan
Dhafer Marzougui
Abdullatif Zaouk
Nabih Bedewi
Azim Eskandarian
National Crash Analysis Center, The George Washington University
20101 Academic Way, Ashburn VA 20147 USA
Email: dmarzoug@ncac.gwu.edu
Email: cdkan@ncac.gwu.edu

Leonard Meczkowski
Turner Fairbank Highway Research Center
Federal Highway Administration, USDOT
6300 Georgetown Pike, McLean VA 22101-2296 USA
Email: Kenneth.opiela@fhwa.dot.gov

This working paper is a compilation of recent efforts and findings intended to solicit feedback on the approach, scenarios analyzed, findings, interpretations, conclusions, and implications for practice resulting from the efforts of the research team. Please forward comments or questions to the authors noted above. These efforts will ultimately be documented and made available to advance research efforts related to this topic and guidance for practice.

ABSTRACT

Secure mailboxes, with locking systems, are becoming more commonly used in recent years. These mailboxes are typically heavier and larger in size than standard mailboxes. These new mailboxes have not been tested and their safety performance when impacted with a vehicle has not been evaluated. In this study, Finite Element (FE) computer simulations coupled with experimental testing is used to investigate the safety of these mailboxes and establish some guidelines on their use and installation. The study is subdivided into three main parts. In the first part a detailed FE model of the mailbox is developed and validated against pendulum crash tests. The second part consisted of conducting parametric finite element analysis, with varied mailbox sizes, heights, mounting configurations, and post sizes, to evaluate the mailbox performance. The varied parameters were selected such that a majority of secure mailboxes are covered in the analysis. The third part of the study consisted of validating the simulations results. A critical case was chosen from the simulations and a full scale crash test with identical parameters was performed.

INTRODUCTION

It has been estimated that over 10,000 deaths occur yearly due impacts with fixed objects. About 2000 fatalities are due to collision into a pole or a post. Under the pole/post support category, the American Association of State Highway and Transportation Officials (AASHTO) estimates that 70 to 100 people die annually in the United States in collisions with mailboxes [1, 2]. Further more, new trends are observed in mailbox sales. New types of mailboxes, such as secure and vandal proof mailboxes, are becoming more popular. These mailboxes are heavier and larger in size that typical mailboxes. Impact into these mailboxes could be significantly more harmful and could increase the number fatalities and serious injuries. It is therefore important to investigate the safety of these mailboxes and to establish some regulations and guidelines that would reduce the fatalities and risk of injuries associated with them.

METHODOLOGY

The objective of this research is to investigate the safety performance of secure mailboxes. These mailboxes come in a verity of shapes and sizes. Also varied support systems are available to mount these mailboxes. Evaluating all these cases through only full-scale crash testing would require a large number of tests and could be cost prohibitive. An approach that makes use of finite element simulations coupled with full-scale crash testing is used in this study.

In the first part of the study, a detailed search was performed to identify currently available secure mailboxes. During the search process, all relevant data, such as mailbox weight, mailbox dimensions, support type, etc., were gathered. Upon completion of the search, a set of mailboxes and support systems were selected for the study. The selection was made in such a manner that the majority of available secure mailboxes are considered in the analysis. Four different mailboxes were selected and used in the study: the “Belaire 20” which weighs 6.4kg (14lb), the “Belaire 16” weighing 10kg (22lb), the “Senator 16” which weighs 15kg (33lb), and the “Senator 16 XL” with a weight 17.7kg (39lb). Two different post sizes were chosen: a 50mm x 50mm x 1.6mm (2”x2”x1/16”) and a 100mm x 100mm x 3.2mm (4”x4”x1/8”) square tubes. A third parameter that was varied in the simulations is the mounting configuration of post to the ground. Three mounting configurations were analyzed. The first configurations, surface mount, consisted of connecting the post to a concrete foundation through four bolts. In the other two configurations, the post was embedded in soil at 300mm (12”) and 600mm (24”) depths.

In the second part of the study, two pendulum tests were performed to validate the secure mailbox model. One of the four chosen mailboxes, the Belaire 20, was used in these tests. The two tests were similar except for the connection of the supporting post to the ground. In the first test, four grade 5 bolts were used to secure the post to the foundation. In the second test, grade 2 bolts were used. A detailed finite element model of the secure mailbox was created and the two test setups were replicated. The model was then exercised to check its validity. Several simulations were performed to identify and correct deficiencies in the model. This process continued until reasonable correlations were obtained between tests and the simulations.
Upon completion of the validations process, a series of simulations were performed. The simulations consisted of impacting the selected mailbox/post/mounting system with a Geo Metro (820C) vehicle. The vehicle impact speed for all simulations was 100km/hr (62mph). The impact location, in all cases, was at the bumper center point. A total of 24 simulations were performed with four different mailboxes, two support posts, and three mounting configurations. Results from these simulations were used to evaluate the safety of these mailboxes.

To validate the study results, a full-scale crash test of the most critical case was conducted and compared to the simulation predictions.

The following sections of the paper provide a summary of the study. In the first section, the two pendulum crash tests that are used for the mailbox model validation are presented. The second section describes the finite element model of the mailbox. The third section shows the model validation process. In the fourth section, the simulations performed to evaluate the safety of secure mailboxes are presented and the results from these simulations are discussed. The last section shows the full-scale crash test that was selected and used to validate the results from this study.

PENDULUM CRASH TESTS

Most previously conducted tests were performed on the traditional tunnel mailboxes. Secure mailboxes are significantly different in shape and characteristics than traditional mailboxes. To validate the finite element model of the secure mailbox, two pendulum crash tests were conducted (Tests 02015 and 02017). The pendulum used in the test consists of a concrete block, two steel blocks which are located at both ends of the concrete, and a frontal steel nose. The height of the pendulum measured from the ground to the center of the nose is approximately 350mm (14”). The total weight of the pendulum is 2000kg (4400 lbs). It is attached to the frame through 4 cables as shown in Figure 1. The cables are 9.1m (30’) in length. The initial speed of the pendulum is achieved by lifting it to a certain height then allowing it to swing freely toward the mailbox. The height at which the pendulum is lifted dictates the impact speed.

The mailbox that was used in the test is the “Belaire 20” design and the supporting post was a 100mm x 100mm (4”x4”) square tube. This selected post is designed for surface mount. The mailbox is connected to the post using four 12.7mm (½”) bolts that came with the mailbox (Figure 2a). The post is connected to the foundation of the pendulum system with a steel bracket (Figure 2b). This bracket was made significantly thicker that the steel post so that it would act as a rigid support. The post is connected to the bracket through four 12.7mm (½”) bolts, which is the manufacturer’s designated bolt size for the chosen post. The bracket is then connected to the pendulum foundation through eight 19mm (¾”) bolts.

Two tests were conducted with the above setup. Both tests were similar except for the strength of the bolts used to connect the post to the steel bracket (Figure 2b). In test 02015 grade 5 bolts were used while in test 02017 bolts of grade 2 were used. Grade 5 bolts use a higher strength material that Grade 2. Comparison between the two tests showed that this difference did not have significant effect on the overall behavior of the mailbox. Similar deformations of the post and mailbox were observed in the two tests. The pendulum accelerations were also similar (Figure 3).
FINITE ELEMENT MODEL DESCRIPTION

A detailed finite element model of the mailbox was created. First, accurate geometry was incorporated in the model. Ensuring correct geometry in finite element models is critical, especially for dynamic analyses. The component mass, stiffness, and inertial properties are directly affected by the geometry. The geometry was extracted from an actual mailbox. Since all components were made of sheet metal, shell elements were used for the parts.

Next, appropriate material properties and thicknesses were assigned to these parts. This was relatively simple since the majority of the mailbox components are made of the same material and have the same thickness. The material model that was used for these components is “piecewise_linear_plasticity” in LS-DYNA [3, 4]. This model is suitable for capturing the behavior of structural metals such as steel and aluminum. The material behavior is isotropic elasto-plastic with strain rate effects and failure. The properties used for this material was extracted from the literature as well as previously conducted coupon tests on similar materials.

Figure 1: Pendulum Setup.

Figure 2: Mailbox Connections.
The final part of creating the model was to incorporate the connections. The components of the mailbox were connected to each other using spotwelds, fillet welds, and bolts. The locations of each the spotwelds in the actual mailbox were identified and a “constrained_spotweld” was created at each of these locations. The upper bolts connecting the mailbox to post were represented using the “constrained_nodal_rigid_body” option in LS-DYNA. Fillet welds, which are located between the post plates and the square tube, were modeled using the “constrained_generalized_weld” option.

The lower bolts were found to have significant influence on the response of the mailbox and had to be modeled in details. To accurately and efficiently represent the bolts, special modeling technique was utilized. In this technique, the bolt is modeled with beam elements to capture its tensile, bending, and shear behavior. By using beam elements, the time step is not controlled by the cross-sectional geometry of the bolt. Hence larger simulation time step and smaller computation time is needed for the solution. Elasto-plastic material model with failure was assigned to the beam elements to simulate the nonlinear and failure behavior of the bolt. The geometry of the bolt is represented by shell elements with “null” material properties. The null shell elements have no effect on the stiffness of the bolts and their size does not affect the simulation time step. They are used to represent the bolt geometry for only contact purposes. Nodes from shell elements are tied to the beam element nodes to transfer the contact forces. This method was found to be very accurate and efficient and has been successfully used in several previous studies [5, 6, 7].

The finite model of the mailbox with its supporting post is shown in Figure 3. The model consists of 35 parts, 14468 nodes, 24 beams, and 12431 shell elements.

MODEL VALIDATION

The validation process consisted of running the simulations, comparing the simulation results to the test data, and if necessary correcting the model. This process is repeated until acceptable comparisons are achieved. Two basic comparisons were conducted: quantitative comparisons where the deformations and general motion of the mailbox is examined and qualitative comparisons where the time history data is evaluated. Based on these comparisons, conclusions were drawn on the accuracy of the model.

The qualitative validation consisted of visual comparisons between the test and simulation to check the accuracy of the model. Crash test video clips from high speed cameras were used to check the
deformation and motion of the pendulum and mailbox. The clips were examined frame by frame and compared to the simulations at the corresponding times in the simulation. This was used to check the timing for weld and bolt failure. It was also used to compare the deformation and motion on the post upon impact with the pendulum. Some of these comparisons are shown in Figure 4.

Figure 4: Sequential Images Comparing Simulation and Test.
The qualitative validations consisted of comparing data collected from the crash test with simulation data. The collected data consisted of accelerations measured from the pendulum. An accelerometer was incorporated in the model at the same locations as the test. During the comparison process both the experimental data were filtered using the same filter (SAE 60 filter). The time history comparisons between the test and the simulations are shown in Figure 5.

![Acceleration and Velocity Plots Comparing Simulation and Test.](image)

Figure 5: Acceleration and Velocity Plots Comparing Simulation and Test.

Key factors that had significant effect on the behavior of the mailbox are strain rate effects, bolt failure, and weld failure. These parameters had to be incorporated in the model before good correlations were obtained between the simulation and the test. During the validation process, iterative simulations were
performed to identify deficiencies in the model and correct them. These deficiencies are often caused by inaccurate assumptions in the model. As an example, initially strain rate effects were not incorporated in the model, in other words, the material behavior was assumed not to depend on the rate of loading. The assumption led to a softer response behavior of the posts and therefore inaccurate simulations. Eliminating this assumption and incorporating strain rate effects corrected this problem.

MAILBOX SAFETY EVALUATION

Once acceptable confidence level is established in the mailbox model, finite element simulations were performed to evaluate the safety performance of secure mailboxes. The simulations consisted of impacting the selected mailbox system with a Geo Metro (820C) vehicle. The vehicle impact speed for all simulations was 100km/hr (62mph). The impact location, in all cases, was at the bumper center point. This setup was selected based on the NCHRP Report 350 recommendations for testing support structures. A total of 24 simulations were performed with four different mailboxes, two support posts, and three mounting configurations. Results from these simulations were analyzed to investigate the safety of secure mailboxes. Upon completion of the simulation analyses, a full-scale crash test was performed on one the simulated cases to validate the simulation results.

Finite Element Models and Simulations Setup

Based on the search that was conducted to identify and categorize current secure mailboxes, a set of parameters were selected for evaluation of their safety performance. These parameters were selected such that the majority of secure mailboxes, supporting posts, and mounting methods are considered in the study. A total of four secure mailboxes were included in the analysis. These include: The Belaire 20, the Belaire 16, The Senator 16, and the Senator 16 XL. Two supporting posts were selected for the analysis, 50mm x 50mm (2”x2”) and 100mm x 100mm (4”x4”) square posts. Three different mounting configurations were incorporated in the analysis: a “surface mount” configuration where the post is connected to a rigid foundation, and two “ground mount” configurations where the post is embedded in soil at 300mm (12”) and 600mm (24”) depths.

For each of these cases a computer model was setup. The methods used in creating these models are similar to the ones used for the validated secure mailbox model. Figure 6 shows four of the twenty four mailboxes models that were created using these methods.
Simulated Cases

Mailbox systems are classified under support structures in the NCHRP Report 350. The report calls for two test conditions before these structures are considered passing the level 3 safety performance. These test conditions consist of impacting the mailbox using an 820kg vehicle with impact speeds of 35 and 100 km/hr. Only the 100 km/hr test was considered in this study. The lower impact speed test is typically less critical for mailbox structures. All 24 simulations were setup as recommended in the NCHRP Report 350. The vehicle finite element model used in these simulations is based on Geo Metro. Its initial speed is set in the model at 100 km/hr. The vehicle model was oriented such that it impacts the secure mailbox model at its center line.

The vehicle, its initial conditions, and orientations were incorporated in the 24 cases and simulations for each of the cases were performed. Results from these simulations were then analyzed to evaluate the safety of the mailbox. The focus, when analyzing the results, was on mailbox intrusion into the occupant compartment through the windshield.

Simulation Results and Discussion

Based on the results, the simulated cases can be classified in three different groups. The cases in each of these groups showed similar overall behavior.

The first group consists of all the cases where 100mm x 100 mm (4”x4”) steel posts are used to support the mailbox. With this type of post, the simulation behavior was similar for all three mounting configurations and with all four mailboxes. The post in these cases, due to its large size, had almost no deformation and remained straight. The post pivoted at ground level and either pulled out of the soil, for in the cases of “ground mount”, or separated from the base, in the case of “surface mount’. The mailbox in these cases remained attached to the post and the mailbox was pushed forward away from the windshield. A sequence of photographs of one of these cases in this group is shown in Figure 7a.
The second group covers eight cases where a 50mm x 50mm (2”x2”) post and a “ground mount” configurations are used. The group includes all four mailbox sizes and the two “ground mount” configurations (12” and 24” embedments). The simulations showed similar behavior for all these eight cases. The post in these cases is significantly weaker than the one used in the first group. It is smaller in size and thickness. During the impact, the post was bent at bumper level. This post was then pulled out of the ground. The connection between the mailbox and the post did not fail in these cases. Consequently, upon impact, the mailbox was pulled downward and hit the hood of the vehicle. Upon impact with the hood, the mailbox bounced upward away from windshield. It was observed in these simulations that the larger the mailbox, the closer it came to hitting the lower portion of the windshield. Similarly, the cases with the 600mm (24”) soil embedment hit closer to the windshield that the cases with the 300mm (12”) embedment. A sequence of photographs of one of these cases in this group is shown in Figure 7b.

The third and final group consisted of the cases where a 50mm x 50mm (2”x2”) post is used in a “surface mount” configuration. This group consists of four cases. In these cases the post was bent at bumper level upon impact. The post was also sheared and separated from the lower plate. In these cases the mailbox impacted the upper portion of the hood and lower portion of the windshield. The simulations showed that the larger the mailbox is, the larger the contact area with the windshield. The worst case scenario was observed with the largest mailbox, the “Senator 16 XL”. It was observed however that even for this worst case scenario, the mailbox did not intrude into the occupant compartment. A sequence of photographs from this worst case scenario is shown in Figure 7c.

**Critical Case and Validation**

Upon completion of the finite element analysis, one of the simulated cases was selected for testing. The purpose of this test is to check the accuracy of the simulation predictions. The mailbox tested was the 17.7kg (39lbs) “Senator 16 XL” supported by a 50mm x 50mm (2”x2”) post and installed in a “surface mount” configuration. The vehicle speed was 100 km/hr.

Figure 8 shows a side by side view of the simulation results and the full scale test. The simulation is shown on the left and the full-scale test on the right. The comparisons show good correlation between the full-scale test and the simulations. Both show that the mailbox impacted the upper portion of the hood and lower portion of the windshield without intruding into the occupant compartment. It can therefore be concluded that the 24 cases studied pass the safety criteria.
Figure 7: Sequential Images Showing Results from Group 1, 2 and 3 Cases.
Figure 8: Sequential Images Comparing Simulation and Test.
CONCLUSIONS

In this study, finite element simulation coupled with full-scale crash testing was used to evaluate the safety performance of secure mailboxes. Detailed model of secure mailboxes were created and validated against pendulum tests. Upon completion of the validations process, a series of simulations were performed. The simulations consisted of impacting the selected mailbox/post-mounting system with a Geo Metro (820C) vehicle. The vehicle impact speed for all simulations was 100km/hr (62mph). The impact location, in all cases, was at the bumper center point. A total of 24 simulations were performed with four different mailboxes, two support posts, and three mounting configurations. Results from these simulations were used to evaluate the safety of these mailboxes.

The most critical impact was observed with “Senator 16 XL” mailbox mounted on a 50mm x 50mm (2”x2”) post. In this case, the mailbox hit the lower portion of the windshield. This case was selected for the full-scale crash testing to validate the simulation results. The test was setup similar to the simulation. The full-scale crash test results confirmed the simulation predictions.

Results from this study showed that current USPS approved secure mailboxes do not show potential intrusions in the occupant compartment if they are correctly installed, i.e. the appropriate supporting system with the appropriate connecting hardware is used. Other cases, with other supporting systems such as wood posts, will be investigated in the second phase of the study.

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