Numerical and Experimental Protective Performance Evaluation of Sacrificial Member Effects on the Protective Structures

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Abstract. Principal objectives of the protective design are on protecting life, property, facility, system device and operations by developing protective design measures that reduce threat level and vulnerability while enhancing structural resilience. Protective design procedure against blast hazard would be accomplished with the threat identification, risk-based assessment, and designing the members and structures based on the proper design requirements. Considerable necessity before the protective design is to find out the various measures reducing the blast effect such as security measures, architectural configuration, and mitigation schemes without any structural strengthening the structure itself. This paper addresses the mitigation scheme to reduce the blast overpressure in general, and then a specific barrier type is introduced as sacrificial structures with the performance verification. The general schemes to reduce the blast pressure by installing barriers is mainly using RC type structures which have typical shapes and sizes. This barrier type has advantages both on installing easiness and cost. In the barrier type sacrificial wall structure, instead of using the normal RC structures, enhanced-cement concrete and composites are useful to improve protective performance and scabbing of the back surface of the RC walls. A series of the wall type RC barriers are modeled and fabricated to investigate and verify blast pressure migration and protective performance based on theoretical and numerical analysis.

1. Introduction
Mitigation of the blast wave pressure and fragments is the key issue in the protective engineering in both military and civil area. Mission of the protective design is on protecting life, property, facility, system device and operations by developing protective design measures that reduce threat level and vulnerability while enhancing structural resilience. Protective design procedure against blast hazard would be accomplished with the threat identification, risk-based assessment, and designing the members and structures based on the proper design requirements.

Necessary prior consideration before the protective design is to find out the various measures reducing the blast effect such as security measures, architectural configuration, and mitigation schemes without any structural strengthening the structure itself.

This paper addresses the mitigation scheme to reduce the blast overpressure in general, and then a specific barrier type is introduced as sacrificial structures with the performance verification. The
conventional scheme to reduce the blast pressure by installing barriers is mainly using RC type structures which have typical shapes and sizes. This barrier type has advantages both on installing easiness and cost. In the barrier type sacrificial wall structure, instead of using the normal RC structures, enhanced-cement concrete and composites [1-3] are useful to improve protective performance and scabbing of the back surface of the RC walls. Enhancement of the protective performance has been analyzed and verified by computational numerical methods and field blast experiments.

2. Computational Analysis

2.1. subsection Analysis Model

A Total of 77 cases are modeled and analyzed to investigate protective performance, comparing between normal strength concrete and enhance-concrete.

![Wall model](image)

**Figure 1.** Wall model

Dimension and properties of the model wall as shown in the Figure 1 are listed as follows and Table 1.

- Wall Dimension (Typical wall in the standard drawings in DMFC [4])
  - 150 x 200 Cm Wall model
  - RC Wall thickness: 20–80 cm
  - Compressive strength: 24~80 MPa
  - Rebar: D16 (Korean Standard)
- Blast Loads
  - 1000lbs GPB – 25ft condition
- Elements
  - 8-nodes solid element (Wall)
  - 2-nodes beam element (Rebar)
- Mesh Size
  - 4x4 cm (Wall and Rebar)
- Boundary Conditions
  - Fixed supports for 4 edges

| Components | Material Properties |
|------------|---------------------|
| Concrete   | Comp. str.: fck=24~80 MPa |
|            | Model:*MAT_CSCM_CONCRETE in LS_DYNA |
| Rebar      | Yield. str.: fy=400 MPa |
|            | Model:*MAT PIECEWISE_LINEAR_PLASTICITY in LS_DYNA |
2.2. Finite Element Analysis
With the computational model described in the 2.1, the following items are verified by FE analysis.
- Deformation or damage level on the walls
- Scabbing on the rear side wall

2.3. Analysis Results
- Damage levels are classified into 3 levels.
  - Severe damage: crack perforates into the whole wall thickness
  - Moderate damage: crack perforates into the wall thickness up to 50%
  - Minor damage: Surface cracks occurred
- Scabbing
  - In the most of walls, scabbing is occurred on the tension side of the wall.
- Damages classified into levels and scabbing occurrence are summarized in the Table 2.

Table 2. Analysis Results (A part of the whole list).

| CASE  | Thickness (mm) | Strength (MPa) | Damage Level | Scabbing |
|-------|----------------|----------------|--------------|----------|
| CASE 1| 200            | 24             | Severe       | ○        |
| CASE 2| 20             | 28             | Severe       | ○        |
| CASE 3| 20             | 40             | Severe       | ○        |
| CASE 4| 20             | 50             | Severe       | ○        |
| CASE 5| 20             | 60             | Severe       | ○        |
| CASE 6| 20             | 70             | Moderate     | ○        |
| CASE 7| 20             | 80             | Moderate     | ○        |
| CASE 8|                | 24             | Severe       | ○        |
| CASE 9|                | 28             | Severe       | ○        |
| CASE 10|               | 40             | Severe       | ○        |
| CASE 11|               | 50             | Severe       | ○        |
| CASE 12|               | 60             | Moderate     | ○        |
| CASE 13|               | 70             | Minor        | ×        |
| CASE 14|               | 80             | Minor        | ×        |
| CASE 15|                | 24             | Severe       | ○        |
| CASE 16|                | 28             | Severe       | ○        |
| CASE 17|                | 40             | Severe       | ○        |
| CASE 18|                | 50             | Moderate     | ○        |
| CASE 19|                | 60             | Moderate     | ○        |
| CASE 20|                | 70             | Minor        | ×        |
| CASE 21|                | 80             | Minor        | ×        |
| CASE 22|                | 24             | Severe       | ○        |
| CASE 23|                | 28             | Severe       | ○        |
| CASE 24|                | 40             | Moderate     | ○        |
| CASE 25|                | 50             | Moderate     | ○        |
| CASE 26|                | 60             | Minor        | ×        |
| CASE 27|                | 70             | Minor        | ×        |
| CASE 28|                | 80             | Minor        | ×        |

3. Blast Experiments

3.1. Test Scheme
Field explosive tests are performed with the 4 test cases as described in the Table 3 and Figure 2-5.
Table 3. Test Cases

| Case | Dimension | Concrete compressive strength (MPa) | Composite |
|------|-----------|------------------------------------|------------|
|      | Size (cm) | Thickness (m)                       |            |
| 1    | 150×200   | 15.0                               | ×          |
| 2    |           | 24                                 | ×          |
| 3    |           | 80                                 | ×          |
| 4    |           | 100                                | ×          |

Figure 2. Test model details

Figure 3. Wall support steel zigs
This should explore the significance of the results of the work, not repeat them. A combined Results and Discussion section is often appropriate. Avoid extensive citations and discussion of published literature.

3.2. Test Results
As expected in the numerical analysis described in 2.3, enhanced-concrete walls showed improved protective performance, and almost identical results compared to the analysis results, even though there were no enough test cases because of the difficulties of the real explosive tests.

Even the enhanced-concrete wall showed improved protective performance significantly, wall thickness has to be over 30 cm at least. Scabbing has occurred at all the test cases as shown in Figure 6 and 6 except the wall cladded with a composite material at the real section (Figure 7). This fact shows that if scabbing is critical consideration for protection of the special facility cladding methods [5] [6] could be a suitable solution than increasing any dimension of the structure itself.
Figure 6. Severe damage

Figure 7. Moderate damage

Figure 8. Scabbing protection by composite cladding
4. Conclusions

Improvement of the protective performance has been verified by applying enhanced-concrete for the barrier type walls as sacrificial structure. Concrete scabbing aspect is also almost avoided by using composite materials as cladding over the back side of RC walls. Improvement of the protective performance has been verified by applying enhanced-concrete for the barrier type walls as sacrificial structure. Concrete scabbing aspect is also almost avoided by using composite materials as cladding over the back side of RC walls.

Research efforts will be continued for more eco-friendly sacrificial structures instead of conventional RC wall types. As the conventional scheme to reduce the blast pressure by installing barriers is mainly using RC type structures which have typical shapes and sizes. This barrier type has advantages both on installing easiness and cost. However deterioration problem of material landscape matters are issued for especially the anti-terror facilities in the city areas. In order to meet on demands of more eco-friendly and mitigation effective solution, green protection scheme has been recently raised so that steel planted type barrier will be proposed.

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