

Optimum Design of a Steel Bar Breaking System in a Sled Test Facility Using LS-OPT

In-Yong Jo

inyong@kostech.co.kr

Young-Gu Chung

young@kostech.co.kr

Hyung-Joo Lee

celhj@www.dbone.com

Jae Moon Lim, Ph.D.

jaemoon@kostech.co.kr

CAE Team,

KOSTECH Inc.,

210 Jung Woo Bldg., 13-25 Youido-Dong, Seoul, Korea

Tel: 82-2-3775-0051

Keywords:

LS-OPT, Optimum Design, RSM (Response Surface Methodology), Sled Test, Steel Bar Breaking System

ABSTRACT

The steel bar breaking system is a component of sled test system for the automobile crashworthiness. The purpose of this study is to optimize the steel bar breaking system in order to extract the crash pulse close to the barrier test result. The design variables are the height, the thickness and the number of each array of the steel bar plates. The optimum design is obtained using DOE (design of experiments) and RSM (response surface method) in the LS-OPT. LS-INGRID is adapted to automate the optimization process because the dimensions of the steel bar plates could be changed in the design process. The optimum design values of the steel bar breaking system are determined to minimize the difference between the crash pulses of the test result and the simulation result.

INTRODUCTION

The purpose of this study is to improve the steel bar breaking system to reproduce the crash pulse (deceleration curve) of the vehicle from the sled test system. The results from the steel bar breaking system provide the characteristics of the sled test system and reduce the period and the cost of the parts or system of the vehicle. Arranging the steel bar appropriately, the deceleration curve from the sled test is to be reproduced similarly to the crash pulse of the vehicle. The design variables are the thickness and the number of the steel bar which variables mainly contribute the optimum arrangement of the steel bar. The space of the steel bar is fixed and is not considered as the design variable.

Two methodologies based on the orthogonal arrays and RSM (response surface methodology) are applied to obtain the optimum design. The orthogonal arrays are used to obtain the initial design and the trend of the appropriate arrangement of the steel bar breaking system. The RSM in the LS-OPT is used to obtain the optimum design of the thickness and the shape of the steel bar.

APPROACH

Sled Test Facility

The sled test facility is represented in Figure 1 and the typical crash pulse from the test and the simulation is represented in Figure 2. The deformed shape of the typical steel bar breaking system is represented in Figure 3.



Figure 1 Sled Test Facility

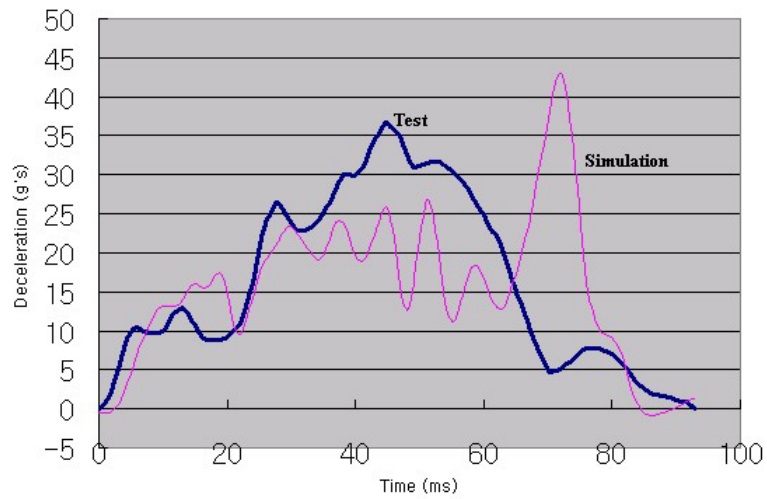


Figure 2 Comparison of Deceleration Curve from Test and Simulation

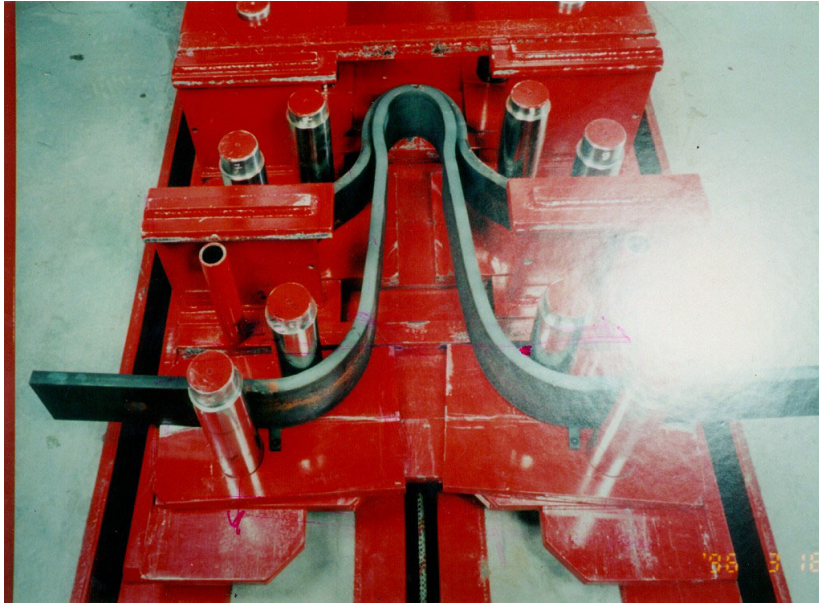


Figure 3 Deformed Shape of Typical Steel Bar Breaking System

Basic Concept of Reproduction of Deceleration Curve

The optimum arrangement of the steel bar is obtained to minimize the error between the standard deceleration curve and the curve generated from the simulation. The error of the deceleration curve between the simulation and the standard one is represented in Equation (1).

$$F = \int_0^{t_{\max}} (g - f)^2 dt \quad (1)$$

Where, g is the deceleration curve from the simulation and f is the deceleration curve from the vehicle test. The optimum arrangement of the steel bar is obtained to minimize the objective function F . The weight of the sled is 350 kg and the thickness of the steel bar is composed of 9t, 12t and 16t. The velocity at the sled test is 30 mph (13.4 mm/ms²).

RESULTS AND DISCUSSION

Results Using Orthogonal Arrays

The design variables (factors) and the levels are represented in Table 1. As shown in Table 1, the $L_9(3^4)$ orthogonal arrays are used to consider four design variables and three levels. The $L_9(3^4)$ orthogonal arrays and the results from the numerical experiment are represented in Table 2. The optimum level of the design variables is represented in Table 3. As shown in Table 3, the optimum level for the optimum arrangement of the steel bar is determined to the first level of the variable A, the first level of the variable B, the third level of the variable C and the third level of the variable D. The value of the objective function F due to the optimum level of the design variables is evaluated 5475 and the result is represented in Figure 4.

Table 1 Design Variables and Levels of Steel Bar Breaking System

Design Variable	Level 1	Level 2	Level 3
Panel Thickness (A)	9	12	16
Number of Panel (B) First Array	1	2	3
Number of Panel (C) Second Array	1	2	3
Number of Panel (D) Third Array	1	2	3

Table 2 Matrix Experiment and Observed Extension Moment

Experiment Number	Variable A	Variable B	Variable C	Variable D	Objective Function F
1	1	1	1	1	14700.28
2	1	2	2	2	12424.74
3	1	3	3	3	6957.21
4	2	1	2	3	5776.43
5	2	2	3	1	16614.96
6	2	3	1	2	24962.81
7	3	1	3	2	38730.45
8	3	2	1	3	54050.32
9	3	3	2	1	106611.5

Table 3 Optimum Design Levels

Variable	Summation of Results	Optimum Level
Thickness (A)	A ₁ : F ₁ + F ₂ + F ₃ = 34082	A ₁
	A ₂ : F ₄ + F ₅ + F ₆ = 47354	
	A ₃ : F ₇ + F ₈ + F ₉ = 199392	
First Array (B)	B ₁ : F ₁ + F ₄ + F ₇ = 59206	B ₁
	B ₂ : F ₂ + F ₅ + F ₈ = 83088	
	B ₃ : F ₃ + F ₆ + F ₉ = 138530	
Second Array (C)	C ₁ : F ₁ + F ₆ + F ₈ = 93712	C ₃
	C ₂ : F ₂ + F ₄ + F ₉ = 124811	
	C ₃ : F ₃ + F ₅ + F ₇ = 62301	
Third Array (D)	D ₁ : F ₁ + F ₅ + F ₉ = 137925	D ₃
	D ₂ : F ₂ + F ₆ + F ₇ = 76116	
	D ₃ : F ₃ + F ₄ + F ₈ = 66783	

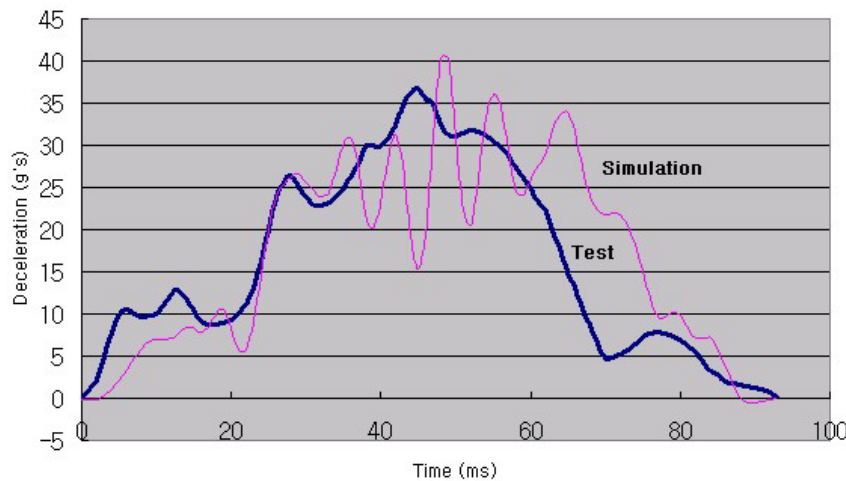


Figure 4 Deceleration Curve for Optimum Values Using Orthogonal Arrays

Results Using LS-OPT

The category of this problem is the shape optimization because the height of the steel bar is changed. That is, the domain and the mesh must be changed. Thus, LS-INGRID is used and interfaced with LS-OPT and LS-DYNA to consider the change of the height and the mesh of the steel bar. This concept is represented in Figure 5. The response model is approximated utilizing the linear function. The design variables are represented in Figure 6. As shown in Figure 6, the design variables are the thickness of the steel bar, the height of the first, the second and the third steel bar. The objective function is the Equation (1). The SAE filter (60 Hz) is used to reduce the numerical noise of the

simulation response.

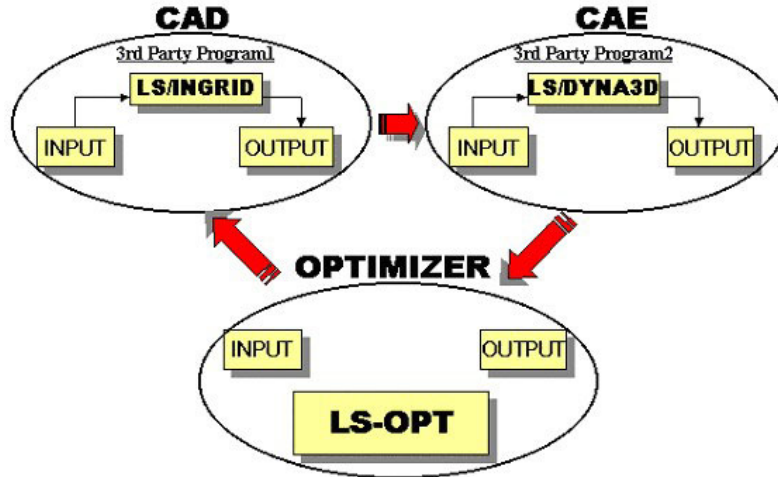


Figure 5 Third Party Software Interface of LS-OPT

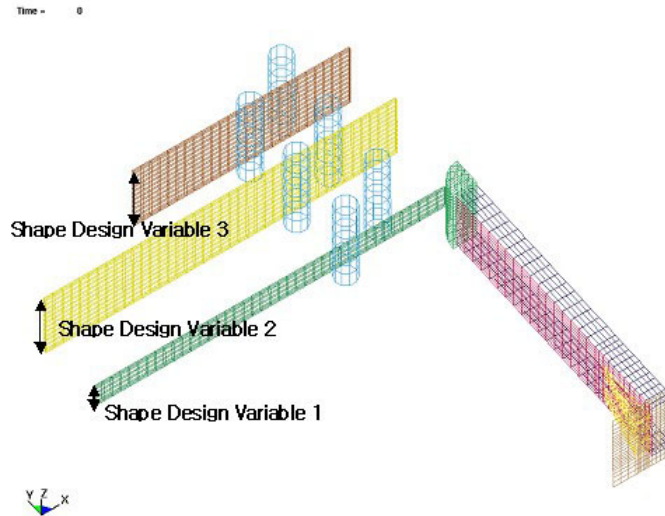


Figure 6 Design Variables for Shape Optimum Design

The result due to the first iteration is represented in Figure 7. The values of each variable are 275 mm of the first height, 275 mm of the second height, 166.6 mm of the third height and 9.549 mm of the thickness. The value of the objective function is 4022.

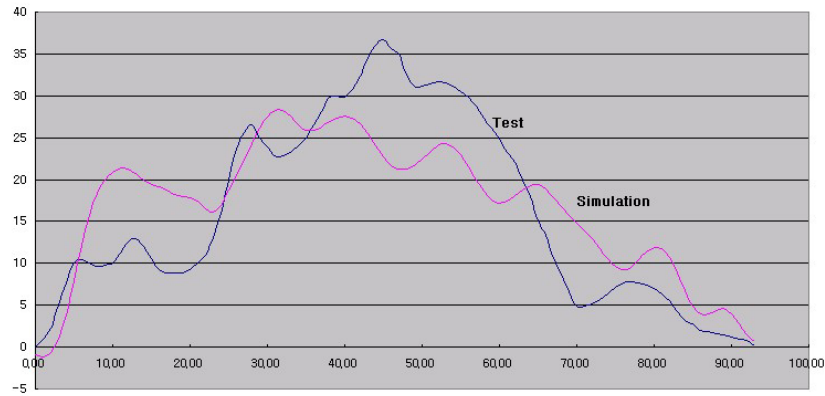


Figure 7 Deceleration Curve after First Iteration

The result due to the second iteration is represented in Figure 8. The values of each variable are 187 mm of the first height, 286.7 mm of the second height, 125.8 mm of the third height and 9.365 mm of the thickness. The value of the objective function is 2951. Based on the engineering concept, the objective function is sufficiently minimized to obtain the appropriate deceleration curve. So, the iteration didn't continue to obtain the convergence.

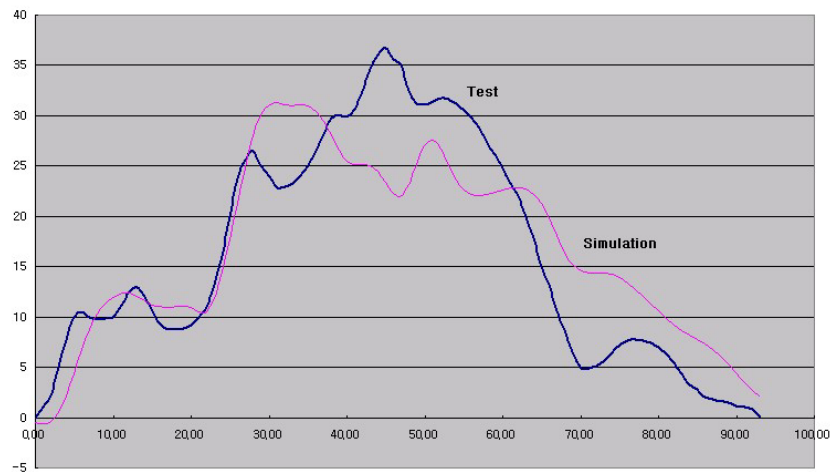


Figure 8 Deceleration Curve after Second Iteration

CONCLUSIONS

LS-DYNA, LS-OPT and LS-INGRID is used to obtain the optimum design of the steel bar breaking system of the sled test facility. The optimum design is obtained to minimize the error between the test and the simulation results utilizing the orthogonal arrays and the RSM in LS-OPT. The interface between LS-OPT and LS-INGRID is effective to solve the problem of the shape optimum design.

REFERENCES

Hallquist, J.O. (2001). LS-DYNA, VERSION 960, KEYWORD USER'S MANUAL.

Hallquist, J.O. (1999). LS-INGRID, A Pre-Processor and Three-Dimensional Mesh Generator for the Program LS-DYNA, LS-NIKE3D, and TOPAZ3D.

Stander, N. (2001). LS-OPT USER'S MANUAL, Design Optimization for Engineering Analysis.

Montgomery, D.C. (1991). Design and Analysis of Experiments, Third Edition, John Wiley and Sons.

