A fundamental study on the optimization design of the cable-typed bridge restrainer with rubber cushion by Genetic Algorithm

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1. Introduction

The Japanese specifications for highway bridges recommends that buffers should be installed on the bridge restrainers to decrease the impact load due to seismic vibrations. However, the design method of the rubber cushion is not regulated, and the maker-determined rubber cushion may not meet the actual need. So, our ultimate goal is to develop more rational design method for the cable-typed bridge restrainer with rubber cushion. In this study, at first, a frame analysis model for cable-typed bridge restrainer with rubber cushion is proposed. Next, a dynamic FEM based Genetic Algorithm (hereinafter referred to as GA-FEM) for the optimization design of cable-typed bridge restrainer is developed. Finally, the optimized result is discussed.

2. Frame analysis model for cable-typed bridge restrainer

As shown in Fig.1, a frame analysis model for cable-typed bridge restrainer was built. In this model, the cable is linear truss model with tension only, and the rubber cushions are nonlinear spring model, as shown in Fig.2, of which the load characteristics is determined by curve fitting with the data from existing hammer experiment[1]:

$$P(d) = a \cdot (0.000217A - 1.1723) \cdot c \cdot f(d) \qquad (1)$$

where

P : Reaction force of the rubber cushion (Unit: kN)

d : Compression displacement of rubber cushion (Unit: mm)

And the other coefficients are determined by rubber properties in Table.1.

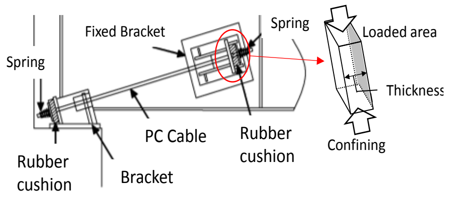
3. GA-FEM analysis for optimization design

3.1 Outline of GA-FEM analysis

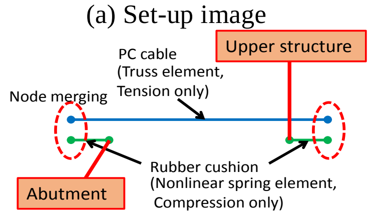
Genetic Algorithm (GA) is an algorithm based on the process of evolution to find the optimized solutions to the real world. In this study, GA is used to find the optimized combination of the bridge restrainer under specific situations. The procedure of GA is shown in Fig.3, especially, the evaluation of different bridge restrainer is performed by FEM analysis.

3.2 Analysis object and model

According to the existing studies, the working velocity of bridge restrainers is under 0.5m/s in most situations, so a simpler one-girder analysis subjected to initial velocity was conducted instead



(a) Set-up image



(b) Frame analysis model

Fig.1 Cable-type bridge restrainer

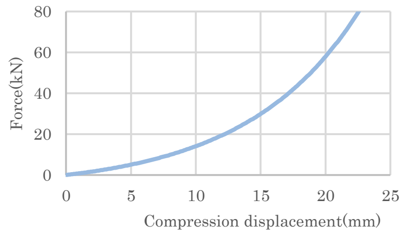


Fig.2 An example of load characteristics for rubber cushion

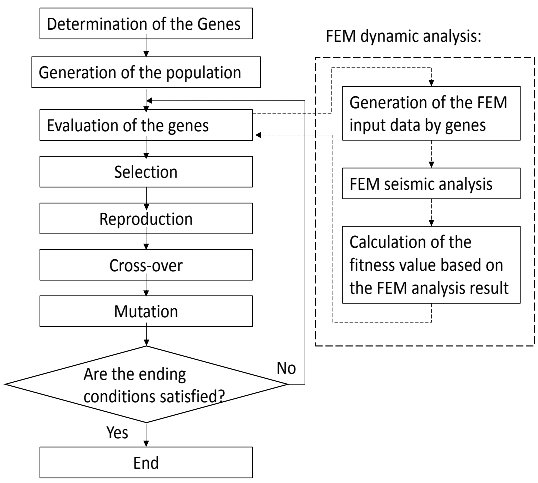


Fig.3 GA-FEM procedure

Table.1 Equation Coefficients

Hardness	45 degree	55 degree	65 degree
a	0.502064	1.0	1.41419
Loaded Area A	Actual Loaded Area(mm^2)		
Confining	No confining		2-face
c	1.0		2.677626
Thickness $f(d)$	$f_{25mm}(d) = 0.00116d^6 - 0.0316d^5 + 0.3371d^4 - 1.6756d^3 + 4.4964d^2 + 0.3476d$ $f_{40mm}(d) = 1\times10^{-7}d^6 + 0.00002d^5 - 0.0004d^4 + 0.0008d^3 + 0.1634d^2 + 1.046d$ $f_{50mm}(d) = 3\times10^{-8}d^6 + 2\times10^{-6}d^5 + 0.0003d^4 + 0.0012d^3 + 0.0529d^2 + 0.702d$		

of doing seismic response analysis. The analysis object is a one span elastic steel bridge with 5 main girders shown in Fig.4. The analysis model is shown in Fig.5, where the black nodes are fixed nodes, and the green nodes are with 0.5m/s initial velocity in the x direction. The blue elements are proposed bridge restrainer model, and the cable length of the bridge restrainer is 2m.

3.3 GA parameter

Binary bits, shown in Table.2, were used to construct the genes. Roulette selection and two-point crossover are applied in GA process. Other necessary GA parameters can be found in Table.3. A stress-based objective function is chosen:

$$f = \min(\sigma_y - \sigma_{\max}) \quad (2)$$

where

$\sigma_{\max}$: the maximum axial stress of the cable

σ_y : the yielding stress of the cable

With this objective function, the bridge restrainer with the minimum stress gap between maximum axial stress and yielding stress would be selected as the optimized result. And during the analysis, the axial stress of the cable should be lower than the yielding stress, which means the bridge restrainer is working without failure. The ending condition is defined as: First, the minimum generation number is 15; Second, the number of the fittest gene is over 60% of the whole generation.

3.4 Result and discussion

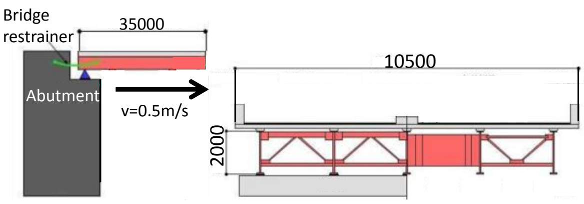
The GA exploring process is shown in Fig.6, which shows that the GA process converges well. When there is no rubber cushion installed, the 1800kN cable should be selected for the bridge restrainer to work without failure under the situation of the analysis. When doing GA-FEM with rubber considered, the final optimized result is the combination of 730.0kN-Hardness55-50mm-2faces, of which the cable is thinner, and the parameter of the rubber cushion is also determined. However, the rubber with 2 face confining is not usually used in the actual design, and to avoid the selection of rubber with confining, an objective function which better satisfies the design requirement is needed.

4. Conclusion

An FEM frame analysis model for bridge restrainer is proposed. A program for the combination of dynamic FEM analysis and Genetic Algorithm is developed, and when the stress-based fitness function is applied, the cable with similar section area with the current design method is selected, and the parameters of the rubber cushion are also determined. In the future, bridge seismic response for gene evaluation is to be conducted in this proposed GA-FEM design method, and various objective function are to be tried out.

Reference:

[1] 結城洋一, 玉井宏樹, 宇野まり子. "形状や拘束条件に着目した緩衝ゴムの緩衝特性に関する基礎実験." 構造工学論文集. A. Vol.61. 土木学会, 2015.



(a) Front View (b) Girder Section

Fig.4 Analysis object (unit: mm)

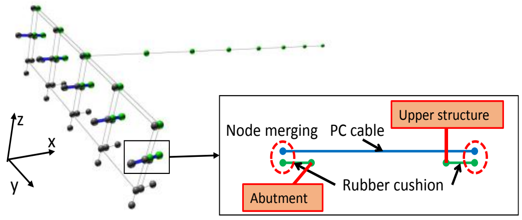


Fig.5 Analysis model

Table.2 Gene construction

Parameter	Value			Code
Cable type, Section area, and Rubber Length	Cable type	Section Area	Length	
	180kN	98.7mm^2	110mm	0000
	260kN	138.7mm^2	155mm	0001
	390kN	208.4mm^2	155mm	0010
	…	…	…	…
	4600kN	2503.2mm^2	520mm	1111
Thickness	50mm			00
	25mm			01
	40mm			10
Hardness	55			00
	65			01
	45			10
Confining	0 faces			0
	2 faces			1

Table.3 Genetic Algorithm Parameter

GA parameter	Value
Gene length	9
Population size	40
Crossover rate	70%
Mutation rate	0.5%

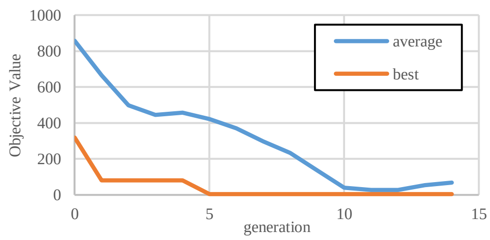


Fig.6 GA exploring process

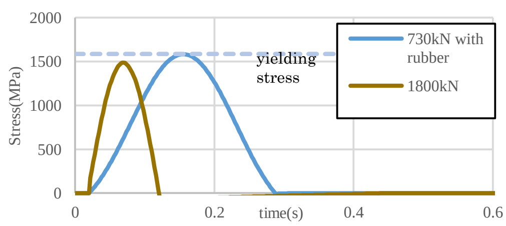


Fig.7 Load time history