

and the bridge in the initial condition, with severe damage and with different column jackets. The figure shows that any of the jackets, designed with established procedures, significantly reduces the probability of exceeding a damage state of a severely degraded bridge. Comparing the three types of jackets, it is observed that the curves for RC and steel jackets are similar into the column elements, generating a lower probability of exceeding a given state of damage for the condition with carbon fibers jackets.

Table 2 shows the damage probability matrix for all conditions analyzed. The probability of some state of damage is 95% for the bridge in its original condition, while when it has slight, moderate or severe damage there is certainty that it will suffer damage. On the other hand, if a steel jackets are made and there is no new degradation, its probability of damage is null, while with concrete and steel jackets the probability is 7.75% and 10%, respectively.

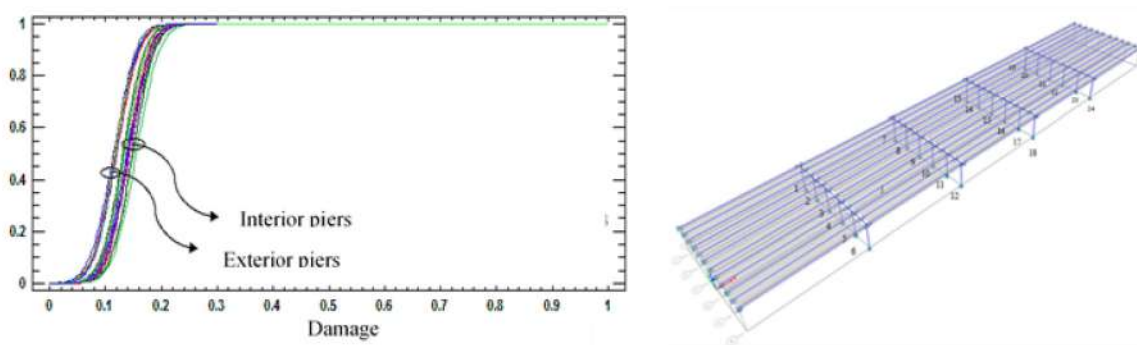


Fig. 5. Pier fragility curves for original condition and number pier scheme

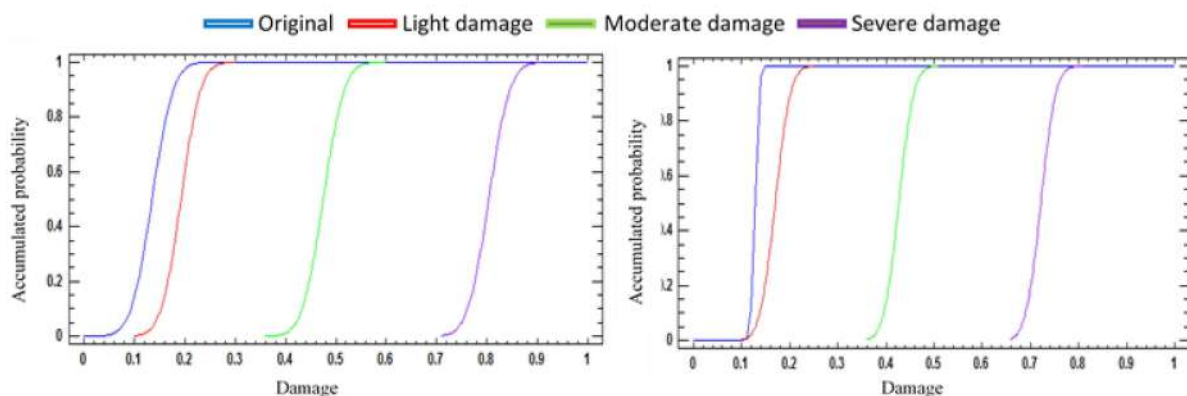


Fig. 6. Fragility curves of the bridge with different degradation levels

8. Conclusions

The need to rehabilitate damaged bridges with the most appropriate technique was the motivation for this work. A regular RC bridge with several continuous spans and with multiple circular columns was studied, it represents one of the most common structural configurations for highway bridges. The structure was designed for a hazardous seismic zone, subsequently modeling the conditions of slight, moderate, and severe damage, degrading the steel and concrete section of the bridge columns and reducing their ductility capacity, all in accordance with the proposals available in the literature. Once the damaged models are established, concrete, steel and carbon fiber jackets are designed for the severely damaged bridge, defining the characteristics of these jackets with established proposals. For all bridge conditions, 300 non-linear analyzes



were performed, considering the probabilistic properties of the mechanical parameters of the materials and the uncertainty of the seismic load with artificial records representative of a typical seismic scenario. The column and bridge damage indices are recorded from analyzes, then the cumulative distribution functions representing fragility curves are adjusted. From this work, the main conclusions are:

- The reinforcement with concrete, steel and fiber jackets was applied only to a state of severe damage, because for other damage states, it is sufficient to repair the concrete covering and small cracks.

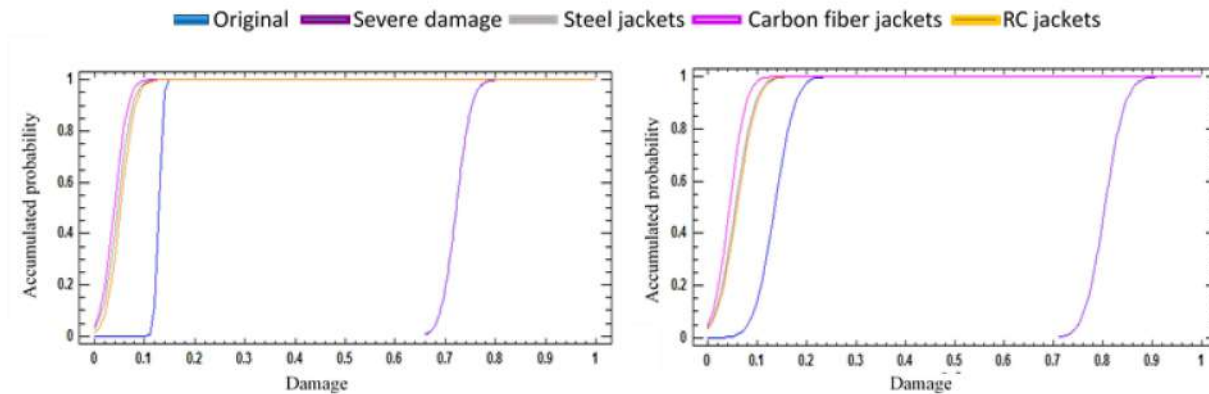


Fig. 7. Fragility curves of pier 10 (left) and bridge (right) with different jackets.

Table 2. Probability of exceeding ID (%) matrix for different conditions.

ID	Damage level	Original	Slight damage	Moderate damage	Severe damage	Steel jackets	RC jackets	Fiber jackets
0.1	No damage	95	100	100	100	0.00	7.75	10.0
0.2	Slight	7.50	40	100	100	0.00	0.00	0.00
0.5	Moderate	0.00	0.00	25	100	0.00	0.00	0.00
0.85	Sever	0.00	0.00	0.00	7.5	0.00	0.00	0.00

- All three techniques are effective in increasing ductility, flexural strength, and shear forces. Regardless of the material used for the jackets, when the design is adequately performed under uniform criteria, for example satisfying ductility demands, it is difficult to declare that one is more effective than the others. This could be noted when making the comparison between the moment-curvature diagrams, capacity curves and finally the fragility curves obtained for the rehabilitated bridges.
- Then, it is possible to affirm that the best system to use will depend on (in addition to evaluated demands) other factors, such as: cost, availability of material, availability of labor, availability of economic resources and experience from the designer.
- When adopting a design criterion specifically based on increasing the resistance, it is necessary to verify that the reinforcement does not reduce the ductility or at least that it continues to satisfy the design demands, a clear example of this is when an element is reinforced with carbon fibers whose unidirectional mesh (which are more common than those used in this project) has the same direction of the element axis, in order to increase flexural strength.



10. Acknowledgements

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12. References

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