Experimental Data Analysis Answer Key

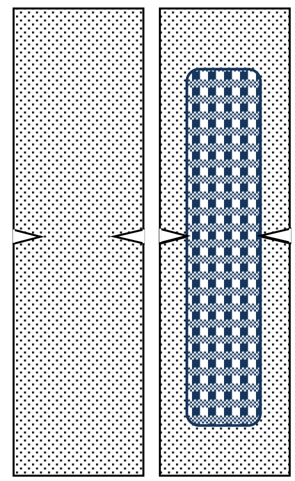
Department of Civil and Environmental Engineering, University of Massachusetts, MA, USA

Data Set 1

Statistics		Unpatched Specimens	Patched Specimens
Sample mean:	$\bar{x} =$	173,418.267	276,733.167
Sample std dev:	$S_x =$	31,917.338	85,681.856
C. variation (%):	$C_v =$	18.405	30.962
Minimum	Min =	114,189	159,747
First quartile:	$Q_1 =$	154,586	212,374
Median:	$Q_2 =$	178,796	256,072
Third quartile:	$Q_3 =$	198,140	360,752
Maximum	Max =	212,164	457,370
10% trim mean:	$\bar{x}_{10\%} =$	176,636.535	270,596.357

Efficiencies: **E_R = 159.576 %** **E_M = 143.22 %**

Patching Configuration



unstressed/one-side patches
$\Delta\sigma = 80$ MPa, $\Delta\sigma_{\omega} = 15$ Hz

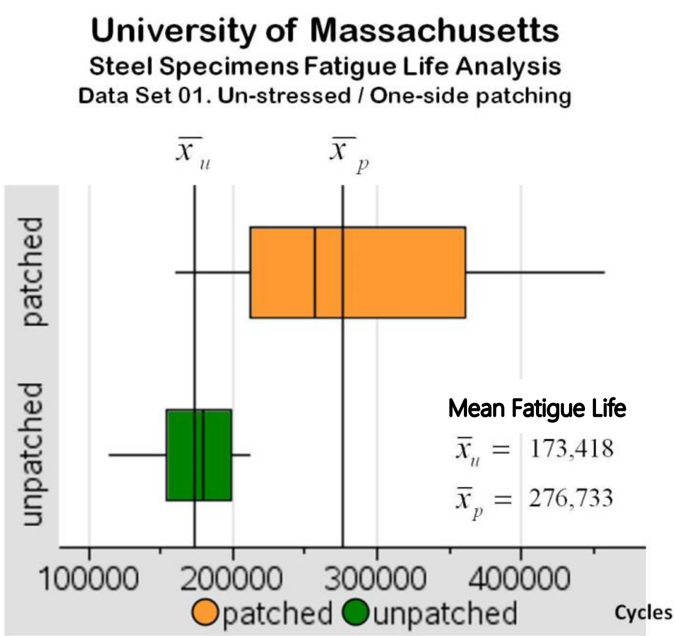


Figure A. The first repair method proposed by the University of Massachusetts is expected to increase the mean fatigue life of cracked steel specimens about 1.6 times and be effective about 75% of the time.

This box-and-whisker plot compares the fatigue life data of patched and unpatched specimens tested at the University of Massachusetts.

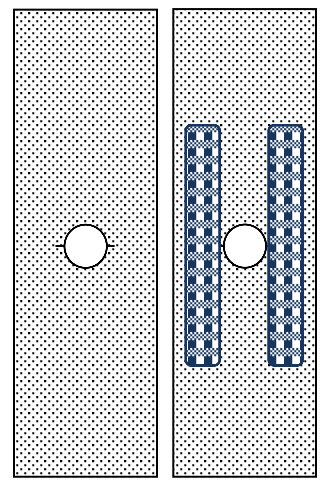
The analysis of Data Set 1 shows that the CFRP patching arrangement used increased the mean fatigue life (MFL) of cracked steel specimens about 1.6 times, but the variability of this extended MFL was about three times greater than the variability of the MFL of the unpatched specimens. In the five-number summary graph for this data set (Figure A), it can be seen that about 75% of the patched specimens performed better than the unpatched specimens; in 25% of the patched specimens the patching was ineffective. Reading the medians of the specimens tested, the *relative median efficiency* is about 1.4, similar to the MFL ratio. In summary, this method is expected to extend the MFL of cracked steel about 1.6 times in only 75% of the repairs.

Data Set 2

Statistics		**Unpatched Specimens**	**Patched Specimens**
Sample mean:	$\bar{x} =$	346,922.125	434,118.313
Sample std dev:	$S_x =$	33,659.442	88,707.717
C. variation (%):	$C_v =$	9.702	20.434
Minimum	Min =	283,173	274,551
First quartile:	$Q_1 =$	326,142.5	377,013.5
Median:	$Q_2 =$	347,281	434,046.5
Third quartile:	$Q_3 =$	368,395	483,028
Maximum	Max =	410,671	617,712
10% trim mean:	$\bar{x}_{10\%} =$	347,432.75	431,906

Efficiencies: **E_R = 125.134 %** **E_M = 124.984 %**

Patching Configuration



unstressed/one-side patches

$\Delta\sigma = 80$ MPa, $\Delta\sigma_{\omega} = 15$ Hz

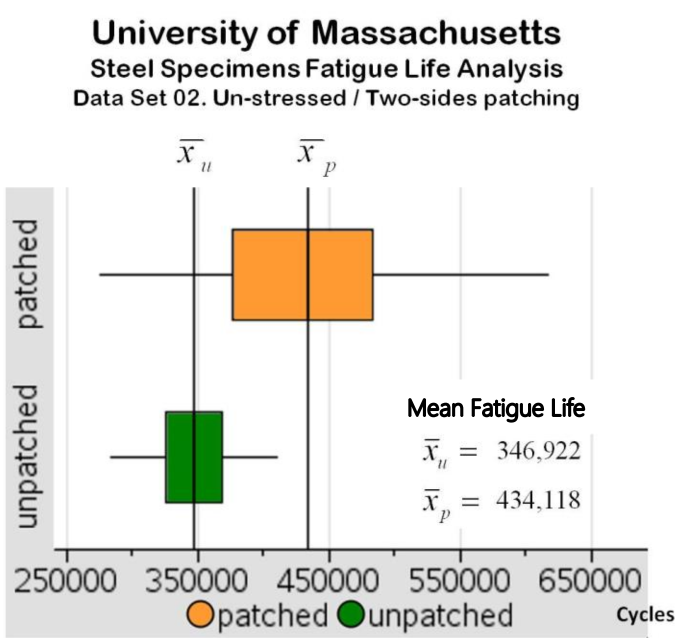


Figure B. The second repair method proposed by the University of Massachusetts is expected to increase the mean fatigue life of cracked steel specimens about 1.25 times and be effective about 50% of the time.

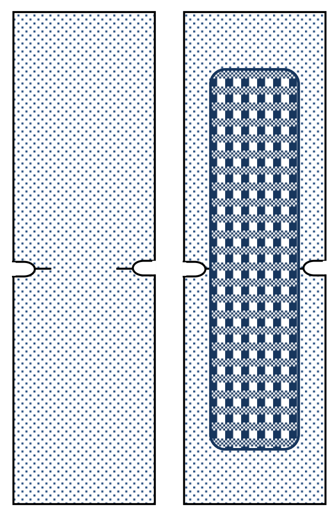
This box-and-whisker plot compares the fatigue life data of patched and unpatched specimens tested at the University of Massachusetts.

The analysis of Data Set 2 shows that the CFRP patching arrangement used increased the mean fatigue life (MFL) of cracked steel specimens on average by 1.25 times, with a variability for this extended MFL about 2.6 times greater than the variability of the MFL of the unpatched specimens. In the five-number summary graph for this data set (Figure B), it can be seen that about 50% of the patched specimens performed better than the unpatched specimens; in practically half of the patched specimens the patching was ineffective. In both, patched and unpatched specimens, the corresponding means and medians were practically identical, no significant difference was found between *median fatigue life ratio* (*patched to unpatched*) and the MFL ratio. In summary, this method is expected to extend the mean fatigue life of cracked steel about 1.25 times in only 50% of the repairs.

School of Civil Engineering, Southwest Jiaotong University. China

Institute for Rehabilitation of Buildings and Structures, University of Braunschweig, Germany

Data Set 3

Statistics		Unpatched Specimens	Patched Specimens	Patching Configuration
Sample mean:	$\bar{x} =$	165,333.333	226,000	
Sample std dev:	$S_x =$	14,105.662	16,236.883	
C. variation (%):	$C_v =$	8.53	7.18	
Minimum	Min =	136,000	198,000	
First quartile:	$Q_1 =$	160,000	216,500	
Median:	$Q_2 =$	166,500	223,500	
Third quartile:	$Q_3 =$	173,000	239,000	
Maximum	Max =	189,000	255,000	
10% trim mean:	$\bar{x}_{10\%} =$	165,900	225,900	
Efficiencies:	**E_R = 136.694 %**	**E_M = 134.234 %**		unstressed/one-side patches $\Delta\sigma = 117$ MPa, $\Delta\sigma_{\omega} = 25$ Hz

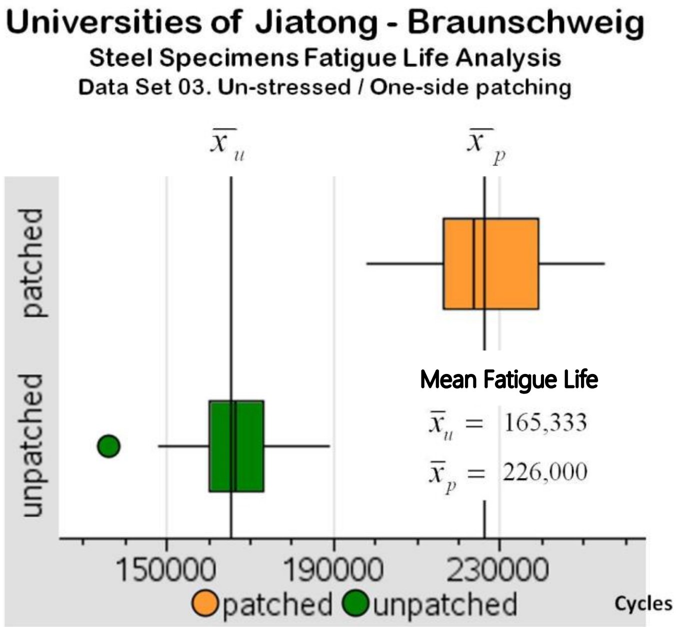


Figure C. The first repair method proposed by the Universities of Jiatong and Braunschweig is expected to increase the mean fatigue life of cracked steel specimens about 1.4 times and be effective 100% of the time.

This box-and-whisker plot compares the fatigue life data of patched and unpatched specimens tested at the Universities of Jiatong and Braunschweig.

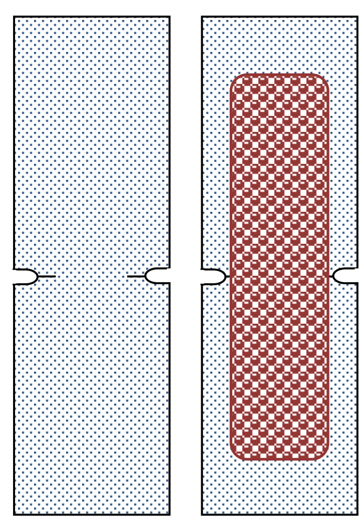
The analysis of Data Set 3 shows that the CFRP patching arrangement used increased the mean fatigue life (MFL) of cracked steel specimens on average by 1.4 times, with a variability practically the same as the variability of the MFL of the unpatched specimens. In the graph of the five-number summary for this data set (Figure C), it can be seen that all the patched specimens (100%) performed better than the unpatched specimens. Reading the medians of the specimens tested, the *relative median efficiency* increased about 1.34 times, very close to the MFL ratio. In summary, this method is expected to extend the mean fatigue life of cracked steel about 1.4 times.

Data Set 4

Statistics		**Unpatched Specimens**	**Patched Specimens**
Sample mean:	$\bar{x}$ =	165,333.333	556, 500
Sample std dev:	S_x =	14,105.662	47,038.669
C. variation (%):	C_v =	8.53	8.45
Minimum	Min =	136,000	474,000
First quartile:	Q_1 =	160,000	525,000
Median:	Q_2 =	166,500	557,500
Third quartile:	Q_3 =	173,000	587,500
Maximum	Max =	189,000	639,000
10% Trim mean:	$\bar{x}_{10\%}$ =	165,900	556,500

Efficiencies: **E_R = 365.593 %** **E_M = 334.835 %**

Patching Configuration



stressed patches @ 1200 MPa

$\Delta\sigma = 117$ MPa, $\Delta\sigma_{\omega} = 25$ Hz

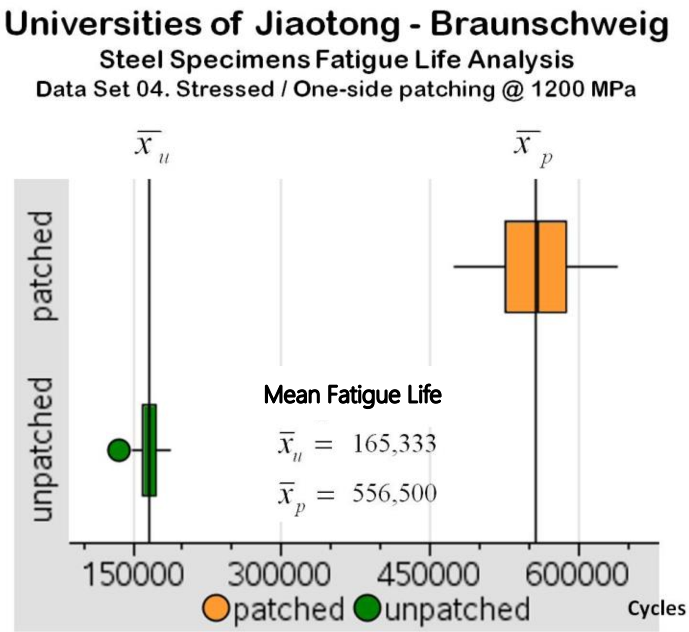


Figure D. The second repair method proposed by the Universities of Jiatong and Braunschweig is expected to increase the mean fatigue life of cracked steel specimens about 3.4 times and be effective 100% of the time.

This box-and-whisker plot compares the fatigue life data of patched and unpatched specimens, tested at the Universities of Jiatong and Braunschweig.

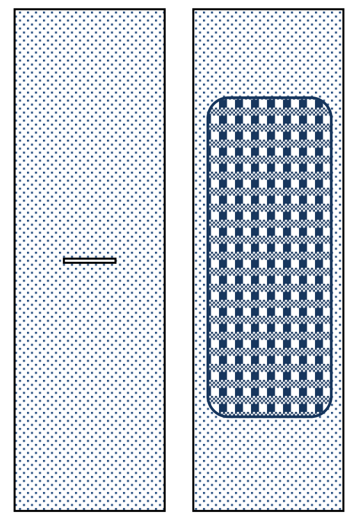
The analysis of Data Set 4 shows that the CFRP patching arrangement used increased the mean fatigue life (MFL) of cracked steel specimens on average by 3.7 times, with a variability very similar to the variability of the MFL of the unpatched specimens. In the graph of the five-number summary for this data set (Figure D), it can be seen that all the patched specimens (100%) performed better than the unpatched specimens. Reading the medians of the specimens tested, the *relative median efficiency* increased about 3.35 times, close to the MFL ratio. In summary, this method is expected to extend the mean fatigue life of cracked steel about 3.7 times.

Data Set 5

Statistics		Unpatched Specimens	Patched Specimens
Sample mean:	$\bar{x} =$	40,143	63,889
Sample std dev:	$S_x =$	1,422.221	9,116.042
C. variation (%):	$C_v =$	3.543	14.269
Minimum	Min =	38,035	47,053
First quartile:	$Q_1 =$	39,065	59,306
Median:	$Q_2 =$	39,873.5	61,536
Third Quartile:	$Q_3 =$	41,375	69,789
Maximum	Max =	42,251	80,963
10% trim mean:	$\bar{x}_{10\%} =$	40,143	63,869.167

Efficiencies: **E_R = 159.576 %** **E_M = 154.328 %**

Patching Configuration



unstressed/one-side patches
$\Delta\sigma = 100$ MPa, $\Delta\sigma_\omega = 2$ Hz

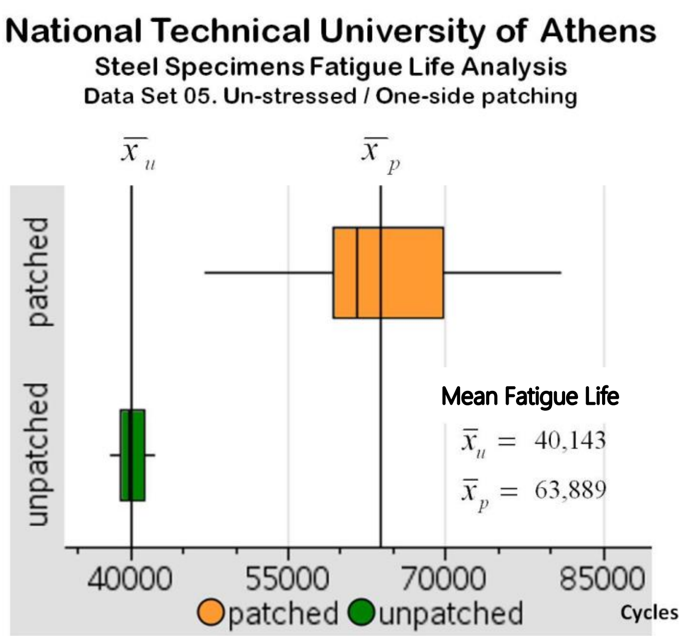


Figure E. The repair method proposed by the National Technical University of Athens is expected to increase the mean fatigue life of cracked steel specimens about 1.6 times and be effective 100% of the time.

The box-and-whisker plot compares the fatigue life data of patched and unpatched specimens tested at the National Technical University of Athens.

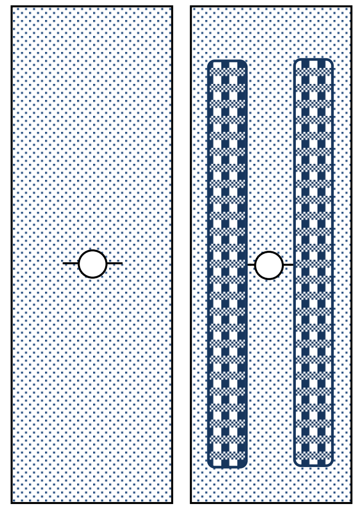
The analysis of Data Set 5 shows that the CFRP patching arrangement used increased the mean fatigue life (MFL) of cracked steel specimens on average by 1.6 times, but the variability of this extended MFL is about 6.4 times the variability of the MFL of the unpatched specimens. In the graph of the five-number summary for this data set (Figure E), it can be seen that all the patched specimens (100%) performed better than the unpatched specimens. Reading the medians of the specimens tested, the *relative median* *efficiency* increased about 1.54 times, very close to the MFL ratio. In summary, this method is expected to extend the mean fatigue life of cracked steel about 1.6 times.

Department of Civil Engineering, Technical University of Denmark, Brovej, Denmark

Data Set 6

Statistics		**Unpatched Specimens**	**Patched Specimens**
Sample mean:	$\bar{x}$ =	470,000	1,433,789.929
Sample std dev:	S_x =	8,769.783	181,903.011
C. variation (%):	C_v =	1.866	12.687
Minimum	Min =	454,000	1,157,369
First quartile:	Q_1 =	465,000	1,328,369
Median:	Q_2 =	471,000	1,394,184.5
Third quartile:	Q_3 =	477,500	1,527,369
Maximum	Max =	481,000	1,767,369
10% trim mean:	$\bar{x}_{10\%}$ =	470,500	1,429,026.75
Efficiencies:	**E_R = 305.062 %**	**E_M = 296.005 %**	

Patching Configuration



unstressed/two-sides patches

$\Delta\sigma = 97.5$ MPa, $\Delta\sigma_{\omega} = 13.5$ Hz

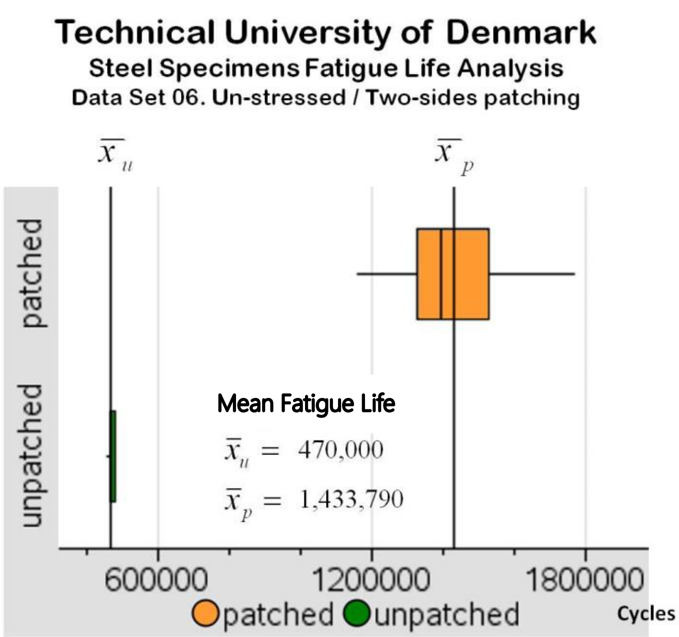


Figure F. The first repair method proposed by the Technical University of Denmark is expected to increase the mean fatigue life of cracked steel specimens about 3 times and be effective 100% of the time.

This box-and-whisker plot compares the fatigue life data of patched and unpatched specimens tested at the Technical University of Denmark.

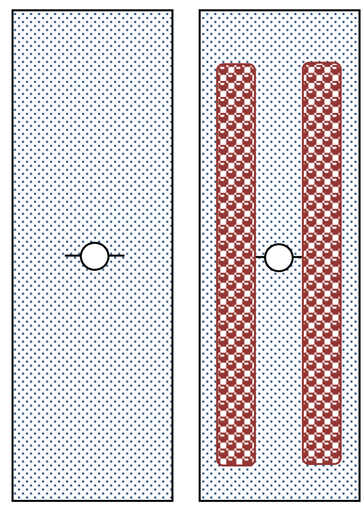
The analysis of Data Set 6 shows that the CFRP patching arrangement used increased the mean fatigue life (MFL) of cracked steel specimens on average by 3 times, but the variability of this extended MFL is about 21 times the variability of the MFL of the unpatched specimens. However, in the five-number summary graph for this data set (Figure F), it can be seen that all the patched specimens (100%) performed much better than the unpatched specimens; the lowest MFL of the patched set is 2.4 times the maximum MFL of the unpatched set. Reading the medians of the specimens tested, the *relative median efficiency* increased about 2.96 times, very close the MFL ratio. In summary, this method is expected to extend the mean fatigue life of cracked steel about 3 times.

Data Set 7

Statistics		**Unpatched Specimens**	**Patched Specimens**
Sample mean:	$\bar{x}$ =	470,000	8,230,000
Sample std dev:	S_x =	8,769.783	2,866,386.092
C. variation (%):	C_v =	1.866	34.829
Minimum	Min =	454,000	3,780,000
First quartile:	Q_1 =	465,000	6,730,000
Median:	Q_2 =	471,000	8,275,000
Third quartile:	Q_3 =	477,500	8,560,000
Maximum	Max =	481,000	15,980,000
10% trim mean:	$\bar{x}_{10\%}$ =	470,500	7,955,000

Efficiencies: **E_R = 1,751.064 %** **E_M = 1,756.900 %**

Patching Configuration (Two-sides patching)



stressed patches @ 13.5 KN

$\Delta\sigma = 97.5$ MPa, $\Delta\sigma_{\omega} = 13.5$ Hz

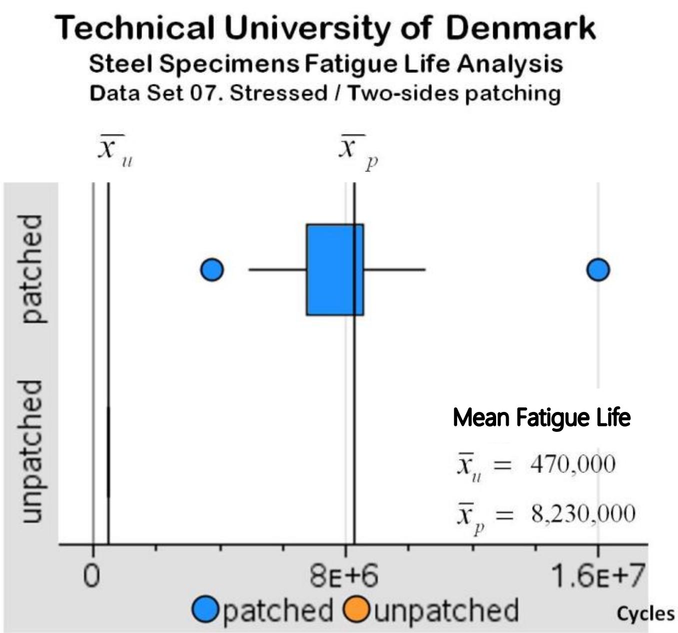


Figure G. The second repair method proposed by the Technical University of Denmark is expected to increase the mean fatigue life of cracked steel specimens about 17.5 times and be effective 100% of the time.

This box-and-whisker plot compares the fatigue life data of patched and unpatched specimens tested at the Technical University of Denmark.

The analysis of Data Set 7 shows that the CFRP patching arrangement used increased the mean fatigue life (MFL) of cracked steel specimens on average by 17.5 times, but the variability of this extended MFL is huge compared with the variability of the MFL of the unpatched elements: 327 times! Analyzing the coefficients of variation, the CV for the patched set is about 19 times greater than the CV for the unpatched set, which indicates that even though this patching method increases the MFL considerably, the variability increases proportionally. A possible explanation of the small variability of the MFL of the unpatched elements could be the use of a very standard quality of the specimens in the experiment. The high variability of the patched elements could be the consequence of using a non-standard patching method, and some steps in this process may not be completely under control.

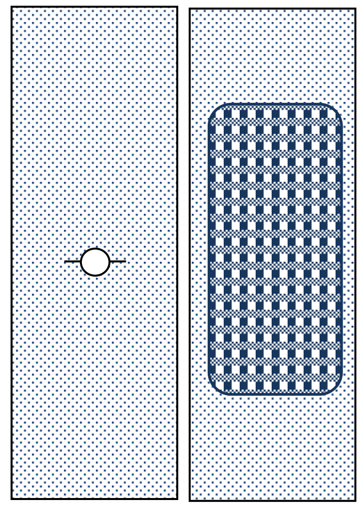
In the five-number summary graph for this data set (Figure G), two outliers in the patched box-and-whisker plot can be observed; the high MFL value that patched specimen achieved is notable, however the 10% trimmed mean of this data set is about the same as its MFL. Reading the medians of the specimens tested, the *relative median efficiency* is about 17.6 times, practically equal to the MFL ratio. In summary, this method is expected to extend the mean fatigue life of cracked steel about 17.5 times.

Data Set 8

Statistics		**Unpatched Specimens**	**Patched Specimens**
Sample mean:	$\bar{x} =$	241,641.5	373,466.25
Sample std dev:	$S_x =$	1,891.644	55,032.453
C. variation (%):	$C_v =$	0.783	14.736
Minimum	Min =	238,333	298,757
First quartile:	$Q_1 =$	240,871.5	342,753.5
Median:	$Q_2 =$	241,614.5	350,812
Third quartile:	$Q_3 =$	242,749	418,245
Maximum	Max =	244,950	478,351
10% trim mean:	$\bar{x}_{10\%} =$	241,641.5	370,448.7

Efficiencies: E_R = **154.554 %** E_M = **145.195 %**

Patching Configuration



unstressed/one side patches

$\Delta\sigma = 135$ MPa, $\Delta\sigma_\omega = 30$ Hz

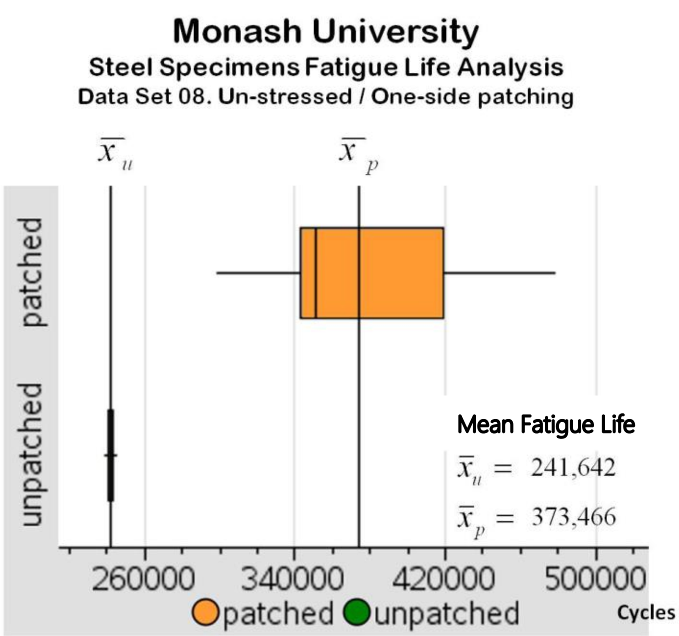


Figure H. The first repair method proposed by Monash University is expected to increase the mean fatigue life of cracked steel specimens about 1.5 times and be effective 100% of the time.

This box-and-whisker plot compares the fatigue life data of patched and unpatched specimens tested at Monash University.

The analysis of Data Set 8 shows that the CFRP patching arrangement used increased the mean fatigue life (MFL) of cracked steel specimens on average by 1.5 times, but the variability of this extended MFL is big compared with the variability of the MFL of the unpatched elements: 29 times. Analyzing the coefficients of variation, the CV for the patched set is about 19 times greater than the CV for the unpatched set, the increase in variability is not proportional to the increase in MFL.

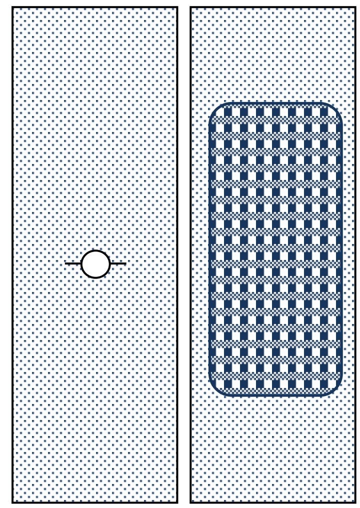
However, in the five-number summary graph for this data set (Figure H), it can be seen that all the patched specimens (100%) performed better than the unpatched specimens. Reading the medians of the specimens tested, the *relative median efficiency* is about 1.45 times, close to the MFL ratio. In summary, this method is expected to extend the mean fatigue life of cracked steel about 1.6 times.

Data Set 9

Statistics		Unpatched Specimens	Patched Specimens
Sample mean:	$\bar{x} =$	241,641.5	1,278,717.583
Sample std dev:	$S_x =$	1,891.644	412,781.576
C. variation (%):	$C_v =$	0.783	32.281
Minimum	Min =	238,333	542,353
First quartile:	$Q_1 =$	240,871.5	1,044,597.5
Median:	$Q_2 =$	241,614.5	1,293,238
Third quartile:	$Q_3 =$	242,749	1,561,380
Maximum	Max =	244,950	1,920,000
10% trim mean:	$\bar{x}_{10\%} =$	241,641.5	1,288,225.8

Efficiencies: **E_R = 529.180 %** **E_M = 536.249 %**

Patching Configuration



unstressed/two sides patches

$\Delta\sigma = 135$ MPa, $\Delta\sigma_{\omega} = 30$ Hz

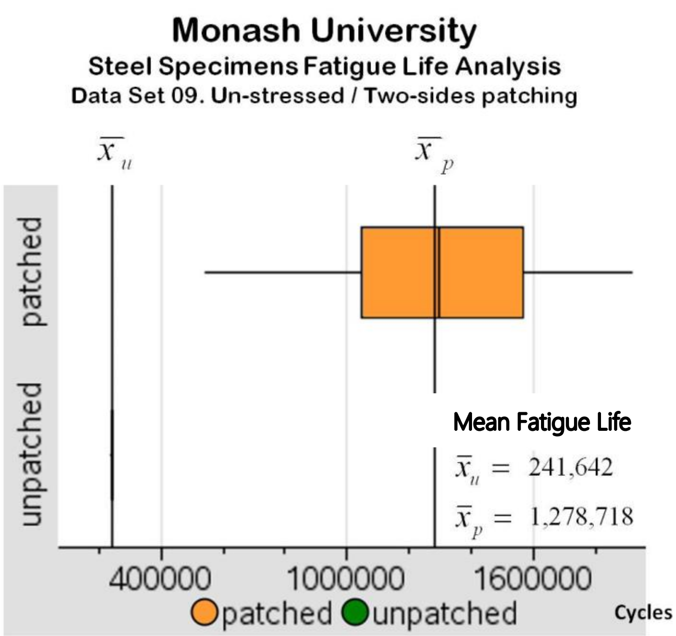


Figure I. The second repair method proposed by Monash University is expected to increase the mean fatigue life of cracked steel specimens about 5.3 times and be effective 100% of the time.

This box-and-whisker plot compares the fatigue life data of patched and unpatched specimens tested at Monash University.

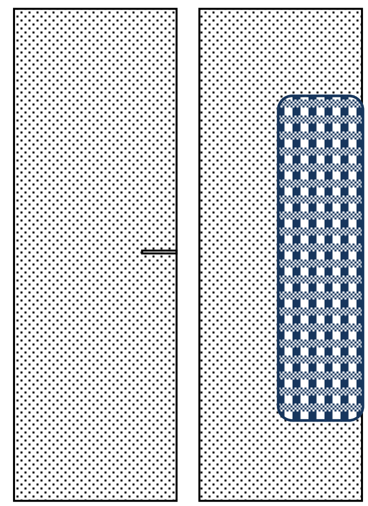
The analysis of Data Set 9 shows that the CFRP patching arrangement used increased the mean fatigue life (MFL) of cracked steel specimens on average by 5.3 times, but the variability of this extended MFL is huge compared with the variability of the MFL of the unpatched elements: 218 times! Analyzing the coefficients of variation, the CV for the patched set is about 41 times greater than the CV for the unpatched set. In this case the variability in the MFL of the patched specimens is not proportional to the increase of the MFL. Again, the differences in variability could be attributed to the steel specimens' consistent quality and to factors that affect the patching process performance being not fully under control.

However, in the five-number summary graph for this data set (Figure I), it can be seen that all the patched specimens (100%) performed better than the unpatched specimens. Reading the medians of the specimens tested, the *relative median efficiency* is about 5.35, practically equal to the MFL ratio. In summary, this method is expected to extend the mean fatigue life of cracked steel about 5.3 times.

Department of Architecture, Built Environment and Construction Engineering, ABC Politecnico di Milano, Milan, Italy

Data Set 10			
Statistics		**Unpatched Specimens**	**Patched Specimens**
Sample mean:	$\bar{x}$ =	196,714	435,110
Sample std dev:	S_x =	9,604.418	142,035.132
C. variation (%):	C_v =	4.883	32,644
Minimum	Min =	181,171	58,400
First quartile:	Q_1 =	187,415	378,037
Median:	Q_2 =	196,714	444,563
Third quartile:	Q_3 =	204,627	512,000
Maximum	Max =	213,690	616,695
10% trim mean:	$\bar{x}_{10\%}$ =	196,554.778	451,370.417
Efficiencies:	**E_R = 221.189 %**	**E_M = 225.995 %**	

Patching Configuration (6mm notch)



unstressed/one-side patches

$\Delta\sigma = 90$ MPa, $\Delta\sigma_\omega = 18$ Hz

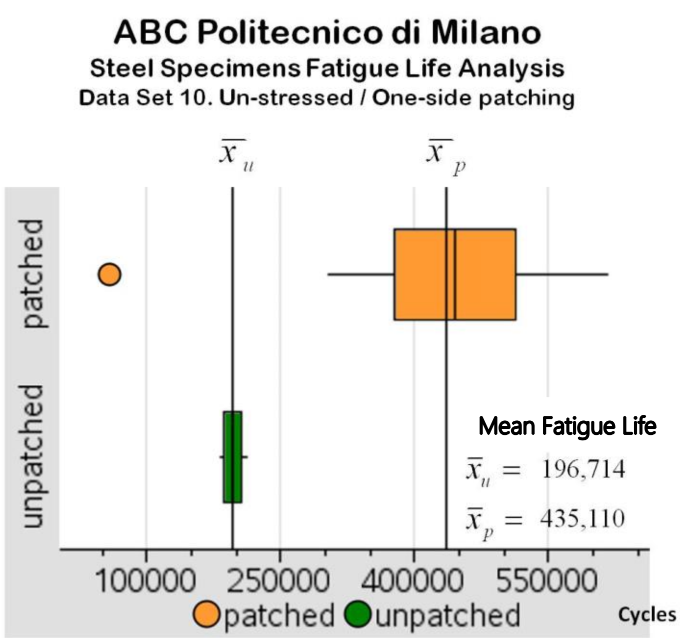


Figure J. The first repair method proposed by the ABC Politecnico di Milano is expected to increase the mean fatigue life of cracked steel specimens about 2.2 times and be effective practically 100% of the time.

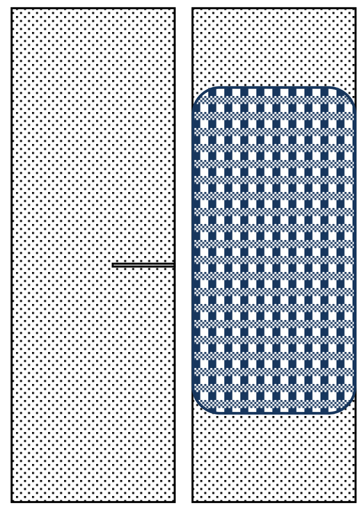
This box-and-wisker plot compares the fatigue life data of patched and unpatched specimens tested at the ABC Politecnico di Milano.

The analysis of Data Set 10 shows that the CFRP patching arrangement used increased the mean fatigue life (MFL) of cracked steel specimens on average by 2.2 times, with a variability about 15 times greater than the variability of the MFL of the unpatched specimens. Analyzing the coefficients of variation, the

CV for the patched set is about 6.7 times greater than the CV for the unpatched set, an increase that could be considered proportional to the change in the MFL.

In the five-number summary graph for this data set (Figure J), it can be seen that all the patched specimens (100%) performed better than the unpatched specimens. Reading the medians of the specimens tested, the *relative median efficiency* is about 2.26, practically equal to the MFL ratio. In summary, this method is expected to extend the mean fatigue life of cracked steel about 2.2 times.

Data Set 11

Statistics		**Unpatched Specimens**	**Patched Specimens**	**Patching Configuration** (15mm notch)
Sample mean:	$\bar{x} =$	29,264	109,760	
Sample std dev:	$S_x =$	1,040.922	29,956.897	
C. variation (%):	$C_v =$	3.557	27.293	
Minimum	Min =	26,899	66,800	
First quartile:	$Q_1 =$	28,818	86,199	
Median:	$Q_2 =$	29,294	107,405.5	
Third quartile:	$Q_3 =$	29,693	129,331	
Maximum	Max =	30,961	172,000	
10% trim mean:	$\bar{x}_{10\%} =$	29,338.222	108,153.333	
Efficiencies:	**E_R = 375.068 %**		**E_M = 366.647 %**	unstressed/one-side patches $\Delta\sigma = 90$ MPa, $\Delta\sigma_\omega = 18$ Hz

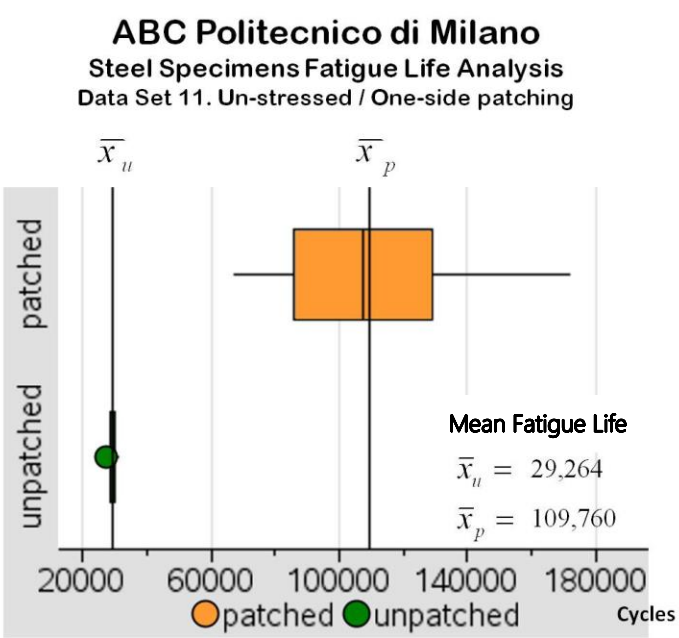


Figure K. The second repair method proposed by the ABC Politecnico di Milano is expected to increase the mean fatigue life of cracked steel specimens about 3.75 times and be effective 100% of the time.

The box-and-whisker plot compares the fatigue life data of patched and unpatched specimens tested at the ABC Politecnico di Milano.

The analysis of Data Set 11 shows that the CFRP patching arrangement used increased the mean fatigue life (MFL) of cracked steel specimens on average by 3.75 times, with a variability about 29 times greater than the variability of the MFL of the unpatched specimens. Analyzing the coefficients of variation, the CV for the patched set is about 7.7 times greater than the CV for the unpatched set, an increase that could be considered proportional to the change in the MFL.

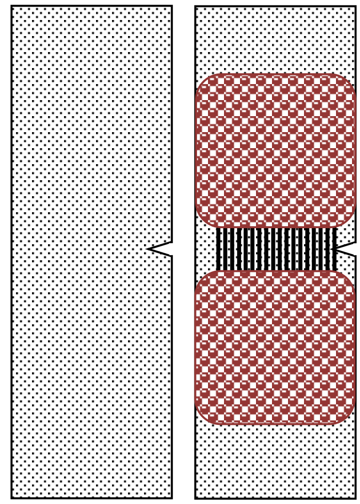
In the five-number summary graph for this data set (Figure K), it can be seen that all the patched specimens (100%) performed better than the unpatched specimens. Reading the medians of the specimens tested, the *relative median efficiency* is about 3.67, very close to the MFL ratio. In summary, this method is expected to extend the mean fatigue life of cracked steel about 3.75 times.

Data Set 12

Statistics		**Unpatched Specimens**	**Patched Specimens**
Sample mean:	$\bar{x}$ =	47,435	990,000
Sample std dev:	S_x =	1,844.008	86,497.6656
C. variation (%):	C_v =	3.887	8.737
Minimum	Min =	44,265	840,000
First quartile:	Q_1 =	45,625	932,000
Median:	Q_2 =	48,176.5	984,500
Third quartile:	Q_3 =	48,622	1,045,000
Maximum	Max =	49,868	1,140,000
10% trim mean:	$\bar{x}_{10\%}$ =	47,496.417	990,000

Efficiencies: **E_R = 2,087.067 %** **E_M = 2,043.527 %**

Patching Configuration



stressed patches @ 30 MPa

$\Delta\sigma = 153$ MPa, $\Delta\sigma_{\omega} = 10$ Hz

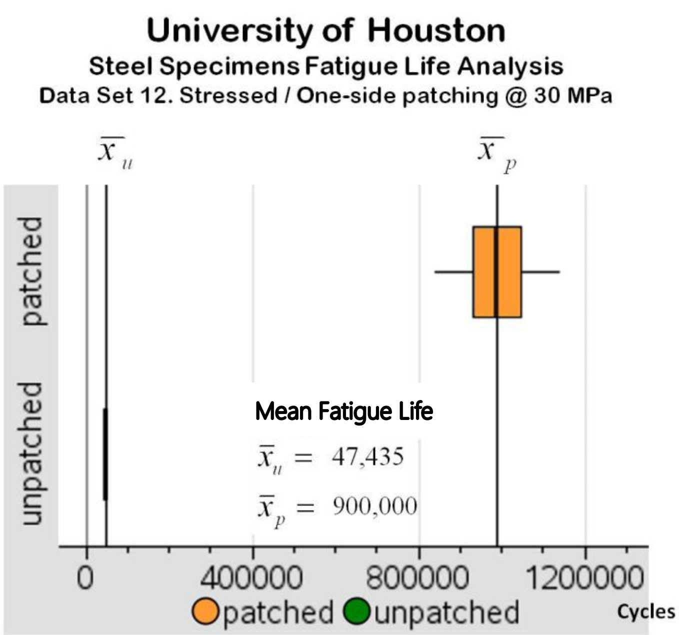


Figure L. The repair method proposed by the University of Houston is expected to increase the mean fatigue life of cracked steel specimens about 21 times and be effective 100% of the time.

This box-and-whisker plot compares the fatigue life data of patched and unpatched specimens tested at the University of Houston.

The analysis of Data Set 12 shows that the CFRP patching arrangement used increased the mean fatigue life (MFL) of cracked steel specimens on average by 21 times, with a variability about 47 times greater than the variability of the MFL of the unpatched specimens. Analyzing the coefficients of variation, the CV for the patched set is about 2.25 times greater than the CV for the unpatched set, an increase that is very proportional to the change in the MFL, and this fact suggests that this patching process has under control most the variables that could cause performance problems.

In the five-number summary graph for this data set (Figure L), it can be seen that all the patched specimens (100%) performed a lot better than the unpatched specimens. Reading the medians of the specimens tested, the *relative median efficiency* is about 20.4 times, practically equal to the MFL ratio. In summary, this method is expected to extend the mean fatigue life of cracked steel about 21 times.

Relative Efficiencies Analysis

As can be noticed from the above data, every laboratory setup has very different experimental conditions: specimens' cracking and patching configurations, stresses applied on specimens, frequency of the stress applied, CFRP specifications and brand, epoxy adhesive used, preparation method used, and many more.

All the above mentioned factors make impossible a direct comparison of the experimental results. But in every experimental setup it is possible to evaluate the relative efficiency of the method: the times the mean fatigue life (MFL) was extended, and this is a good point of comparison.

The following table summarizes the relative efficiencies of every repair method analyzed:

CFRP Patching Relative Efficiencies Summary

Data Set	Research Center	Relative Efficiencies % (E_R, E_M)	
1	*Department of Civil and Environmental Engineering* University of Massachusetts, MA, USA	159.576	143.220
2	*Department of Civil and Environmental Engineering* University of Massachusetts, MA, USA	125.134	124.984
3	*School of Civil Engineering,* Southwest Jiaotong University, China *Institute for Rehabilitation of Buildings and Structures,* University of Braunschweig, Germany	136.694	134.234
4	*School of Civil Engineering* Southwest Jiaotong University, China *Institute for Rehabilitation of Buildings and Structures* University of Braunschweig, Germany	336.593	334.835
5	*School of Naval Architecture and Marine Engineering* National Technical University of Athens, Greece	159.154	154.328
6	*Department of Civil Engineering* Technical University of Denmark, Brovej, Denmark	305.062	296.005
7	*Department of Civil Engineering* Technical University of Denmark, Brovej, Denmark	1,751.064	1,756.900
8	*Department of Civil Engineering* Monash University, Clayton, Victoria, Australia	154.554	145.195

9	*Department of Civil Engineering* Monash University, Clayton, Victoria, Australia	529.180	536.249
10	*Department of Architecture* *Built Environment and Construction Engineering* ABC Politecnico di Milano, Milan, Italy	221.189	225.995
11	*Department of Architecture* *Built Environment and Construction Engineering* ABC Politecnico di Milano, Milan, Italy	375.068	366.647
12	*Department of Civil Engineering* *Cullen College of Engineering* University of Houston, TX, USA	2,087.067	2,043.527

A graphical display of the above data (Figure M) makes it easy to identify the most efficient repair methods. Two methods had an outstanding performance—the second method proposed by the University of Denmark and the one proposed by the University of Houston. Both performances extend the MFL about 20 times (17.5 and 21.5, respectively).

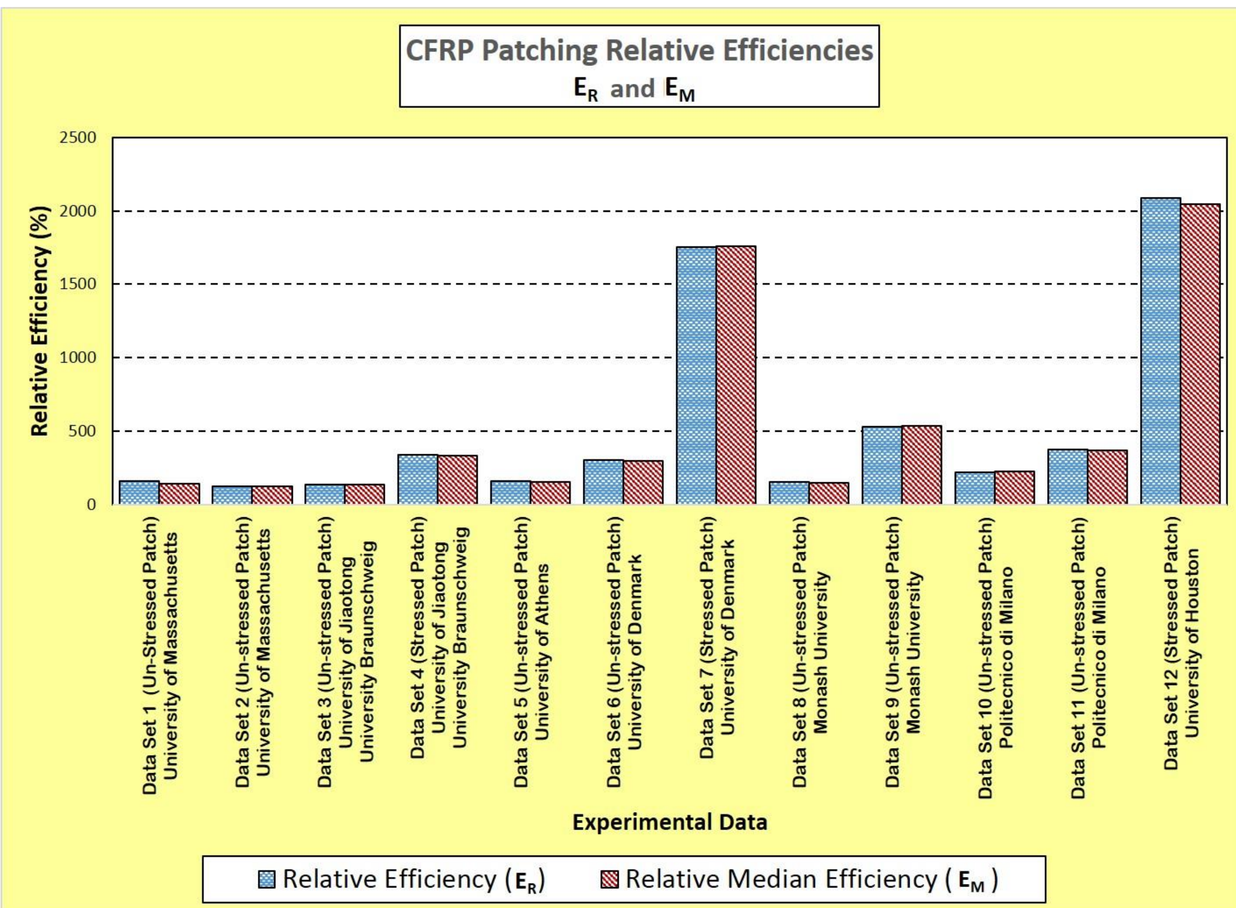


Figure M. *CFRP Relative Efficiencies Graphical Comparison*.
From the direct comparison of the relative efficiencies, it can be concluded that the best repair methods proposed come from the University of Denmark and the University of Houston.

It is also notable that the best repair methods proposed were those using pre-stressed patches, as can be easily seen in a *Pareto Chart of the Relative Efficiencies* (Figure N).

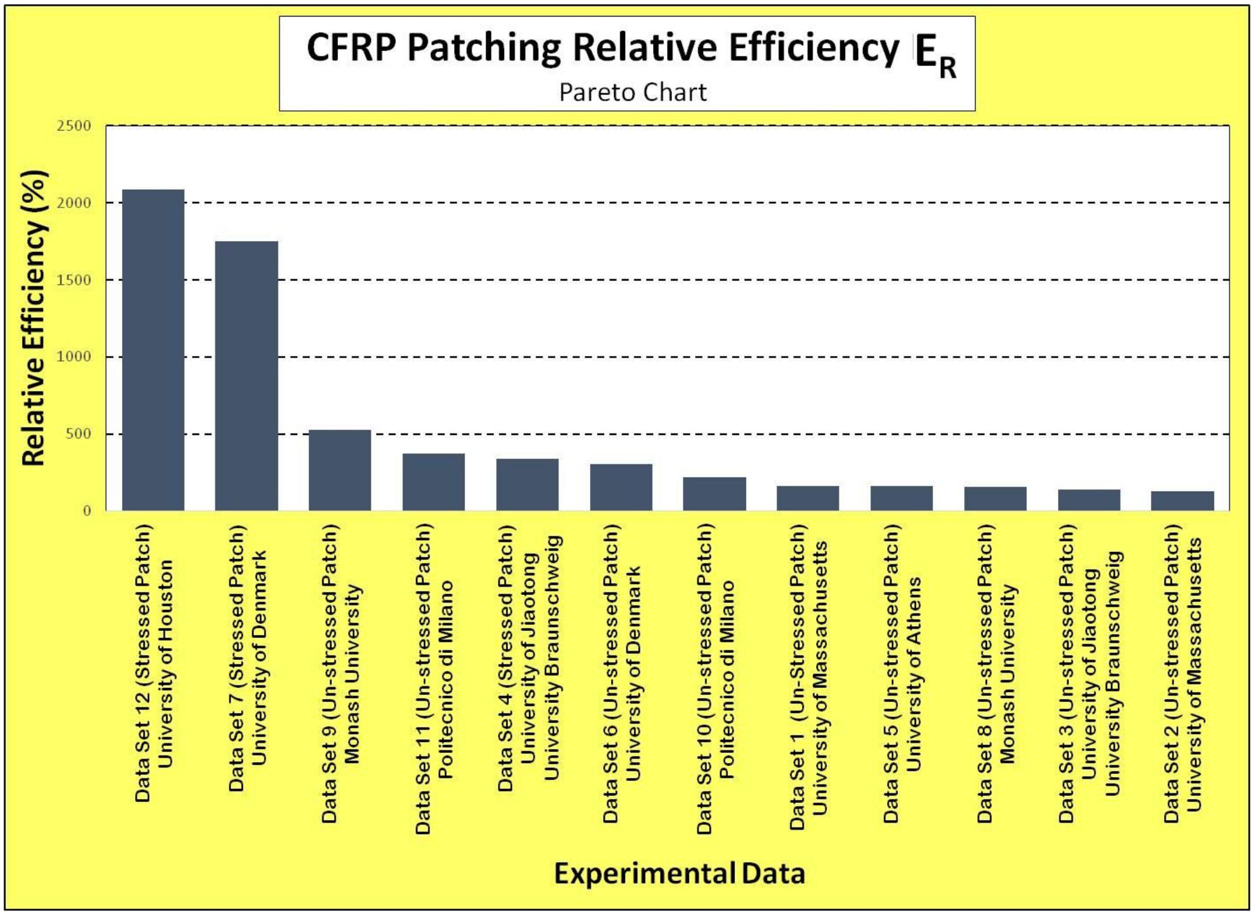


Figure N. *CFRP Relative Efficiencies Pareto Chart*. In this Pareto chart, it can be seen that the repair methods using pre-stressed CFRP patches are among the first five most-efficient procedures.

In conclusion, the best proposed cracked steel repair method was the CFRP-NiTiNb pre-stressed patches developed in the Cullen College of Engineering at the University of Houston.

It is important to make students aware that in real life, additional constraints must be considered in order to make a final choice and purchase: procedure cost, implementation time, implementation plan, quality control, warranties, maintenance schedule, and emergency response time are just some of the important factors to be considered. Be sure that students include mention of these constraints in their preliminary report to the mayor and city council.