Investigation the factors affecting the integrity of FRP-reinforced sheet resistance in bending concrete beams

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Abstract: Beams retrofitted with FRP may come to failure, due to different reason; and several models of the separated FRP boundary and resistance at the FRP junction to concrete is done and factors included in the calculation of the capacity of the beams are: Compressive strength of concrete, Mechanical properties of steel, cement and FRP, width and thickness FRP, beam cross-section dimensions, sections of steel and etc .and variables for each model are different. But when retrofitting buildings, certain variables such as retrofitting buildings of steel, compressive strength of concrete, steel and mechanical properties are not specified. For future research to analysis existing models, it is necessary to obtain the sensitivity of each variable in the model. In this study, a sensitivity analysis of model variables, continuity sheet resistance of FRP-reinforced concrete beams in bending with changes in variables over a certain percentage of the variable is obtained**.** Graphs and sensitivity analysis are presented for each model.
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Keywords: Sensitivity analysis, Reinforced bending beam - FRP Sheets

Introduction:

Poor quality concrete, inappropriate reinforcement, bad performance concrete, inferior materials and etc. are the main problems of reinforced concrete structures [1]. According to the cost of structure substantially renovation, to strengthen the weak structures, and repair damaged structures in recent years, this issue have been widely discussed and many studies have been carried on [2]. In our country, there are lots of old buildings that most of them are in short and medium order with office and educational use [3]. Improve a wide range of engineering services and activities in different purposes, which may include technical, economic, social, cultural, political, aesthetic which have been implemented [1]. Strengthened means increase the strength of weak members against bearing loads and repair means increase the strength to the bearing for damaged organs [2].

For example, the following guidelines can be used singly or in combination with each other to improve the building to be used:

- Local correction of structural elements which have unsatisfactory performance in earthquake condition
- Eliminate or reduce irregularities in existing buildings
- Provision of lateral stiffness for whole structure
- Provide the necessary resistance for whole structure
- Reduced mass of buildings
- To complete the orientation of tension
- Increased integration of buildings with the coil ratings
- Change of land use to reduce the level of expected performance of buildings
- The application of seismic isolation systems.

In this regard, two aspects of retrofitting hard strength is assessed [1]. Seismic retrofitting of existing structures on three parameters: strength, hardness and ductility are essential would run: [4].

Designed to withstand the additional loads, improve deficiencies caused by aging, increased ductility structures, etc. In recent years retrofitting concrete structures using fiber reinforced polymer (FRP) has enjoyed considerable growth [5] [6]. The use of steel plates for strengthening reinforced concrete that is common and has been replaced by FRP [7]. The end of 1970, the first practical applications of repair or retrofit with external amplification was carried out in Belgium [8]. Beams for flexural strength, tensile side of the sheet is attached to the beam, the adhesive sheet funds increased vertical beams near the abutments shear capacity of the beams [9]. The use of FRP sheets as new materials are used in the construction industry for strengthening and repair of reinforced concrete structures [10]. The main advantages of this new material in front of traditional materials can lose weight, high strength; good durability, high tensile strength and elastic coefficient accept them mentioned. On the other hand, the FRP materials are highly resistant to corrosion in alkaline and saline environments are considered, so some researchers as an alternative material for steel materials in corrosive environments have been proposed [11] [12] [13]. The

experimental study of the bending failure of RC beams strengthened with FRP sheets are:
1- Bending failure as failure of FRP sheets
2- The bending failure of flexural concrete crushing in compression
3- Shear failure
4- Separation of the concrete cover of the longitudinal bars from the end of FRP sheets
5- Removable glue the ends of FRP sheets
6- Separation of FRP plate flexural cracks
7- Separation of FRP plate flexural cracks - shear [14] [6].

Concrete beam with FRP sheets stick increase the percentage of longitudinal reinforcement, the percentage of FRP, concrete compressive strength and mechanical properties, the rate of deterioration of concrete and etc [2] [15].

Literature Review:

Extensive research in theoretical, experimental and numerical monitoring in the field of bending beams reinforced with GFRP or CFRP sheets of researchers have taken place. Among the various methods for the recovery and re-empowerment beams (RC) damaged, it has attracted a wide range of researchers, GFRP and CFRP sheets sticking to the outer surface of the tensile zone of the beam. Two reasons, first, ease of operation and high impact strength and bending stiffness of the beam other than the application of these methods have a critical role [16]. M. Accardi & L La Mendola on stress transfer between concrete and FRP plates have been doing research [17]. Houssam Toutanji et al. showed in a study that examined the relationship of bond strength [18].

Büyüköztürk FRP-concrete system and Tzu-Yang Yu failure were studied [19]. Riadh Al-Mahaidi and colleagues conducted a study on CFRP strengthened by shear [20]. Edalati M. and Irani F., have investigated sheet of paper on the mechanical interface between the concrete and FRP, especially the stress distribution in the concrete, the FRP plate and adhesive layer at the end of their connection to each other deaf [16]. Karimi A. and Anwar S., investigated an article entitled studied the connection of external beam finite elements - concrete columns reinforced with FRP sheets under seismic loads parameters affecting the behavior of junctions reinforced with FRP sheets under seismic loads, FRP sheets and prevention of detachment were examined [21]. Mohammad Reza Ghasemi et al. in an article entitled numerical flexural behavior of reinforced concrete beams strengthened with FRP composite materials using the finite element method to investigate the flexural strengthening of reinforced concrete beams strengthened with FRP, and the parameters flexural behavior of the components. Some of these parameters can influence the direction of the fibers relative to the longitudinal axis of the beam, number of layers, thickness, material, width and length of the composite, arrange layers and other parameters related to the properties of the concrete member concrete compressive strength, longitudinal tensile reinforcement area pointed out [22]. Mohammad Reza Esfahani and Mohammadi T., taking advantage of numerical methods and experimental results, the flexural behavior of reinforced concrete beams strengthened with FRP sheets studied [23]. Arabzadeh A. and Mahanpour H., in an article entitled laboratory studies on shear strength of CFRP sheets deep double the effect of CFRP sheets on shear capacity of deep beams have died [24]. Momeni K., and Mazloum M., FRP rebar concrete bond in an article entitled modeling software Abaqus stretch out on the strength of FRP bars made [25]. Rakhshanmehr M., et al., in a paper strength of fiber reinforced polymer reinforcement bond between FRP and concrete beams were examined by the patchy [26]. Sobuz et al. were using FRP reinforced concrete beams [27]. Behavior of RC beams strengthened with FRP Owen Arthur Rosenboom to be examined [28]. Research of Mônica Regina Garcez et al. pre-stressing FRP sheets for strengthening carried out [29].

Researchers who have done research in frontier areas of strength models include: Tanaka (1996), Hioky and Wu (1997), Maada et al. (1997), Taljestin (1994), Hoolmkempfir (1994), Roustasi (1997), Yoyan and Wu (1999), Yoyan et al. (2001), Van Gemert (1980), Khalifa et al. (1998) [7] [30] [31] [32] [33] [34] [35] [36] [37] [38] [39] [40] [41] [42].

Among those who have done research on the strength of FRP sheets can be noted: Ehlers (1992), Ehlers and Moran (1996), Smith and Tang (2003), Tang and Yao (2007), Ehlers et al. (2004), Johnsez (1997), Ahmad and Vangemert (1999), Raof and Zheng (1995 - 1996 - 1997), Wang and ling (1998), Raof and Hasan (2000), Ziraba et al. (1994), Varastehpour and Hamlyn (1997), Sadatmanesh and Malek (1998) and Tamilian et al. (1999) pointed out [7] [43] [44] [45] [46] [47] [48] [49] [50] [51] [52] [51] [7] [53] [54] [55] [56] [57] [58] [59] [60] [61] [62] [63] [64] [65] [66] [67].

Methods

Sensitivity analysis to study the effects of input variables, output variables is called a statistical model. In other words, a way to change the inputs to a statistical model as an organized, systematic effects that could predict the change in model output [68] [69] [70]. Sensitivity analysis is used when the primary problem is that the final optimization

solutions obtained are then asked to analyze the problem in terms of the following:
- Changes in constraints.
- Changes in the objective functions coefficients of the variables.
- Changes in the value of the coefficient restrictions.
- Add a new variable to the objective function.
- Adding new constraints [71] [72] [73].

There are several methods for sensitivity analysis with respect to the appropriate method should be selected. The first method appears to be derived from the sensitivity analysis and comparison of changes in the variables of interest for each of the variables is the same change. This method is appropriate when the variables range similar to each other. Another method that can be used in the sensitivity analysis, changes in specific variables to be varied in the range of percent. This method is used more times. A portion of the unknown function and a variable effect on it is not exactly clear, so this method can be varied to create a real function [71] [73].

There are also issues that actually limits or constraints are very flexible and you can use this method to open, because no matter how close we were to the border restrictions or limitations have been violated and virtually no limit on how much you're supposed to do. In this study, the research results of other researchers who have been active in this field, flexural strength and adhesion between the FRP sheets have found and a sensitivity analysis for each of the existing models, the factors affecting the integrity of the sheet resistance of FRP-reinforced concrete beams in the deflection is obtained [73].

In this study, researchers found that the models linkage sheet resistance of FRP-reinforced concrete beams in bending is available. The second method, sensitivity analysis is used to model the variables of the model sensitivity analysis and the sensitivity of the model parameters is obtained. Factors affecting the integrity of the sheet resistance of FRP-reinforced concrete beams in bending are achieved.

Analysis of Results

Introducing the variables of the models linkage sheet resistance of FRP-reinforced concrete beams in bending are:

f_c': Compressive strength of cylindrical concrete specimens

E_{frp} : Modulus of elasticity of FRP sheets

t_{frp} : Thickness of FRP sheet

E_s C: Modulus of elasticity of steel bars

b : Width of the concrete beam

b_{frp} : Width of FRP sheet

h : The overall height of the beam

A_s : Sectional area of the tensile bars

A_s' : Cross bars of pressure

c : Tensile zone of the concrete cover

c' : Cover concrete in the compression zone

S : The distance between the pitchers

A_{sv} : Sectional area pitchers

f_{yv} : Failure stress pitchers

a : The distance between the fulcrums closer to the end plate

a_1 : Extended load

a_2 : Concentrated load

a_3 : Concentrated moment

B : The shear zone

E_a : Modulus adhesive

t_a : The thickness of the adhesive layer

G_a : The shear modulus of the adhesive

M_0 : Bending moment end of plate

V_0 : Shear in end of plate

q : Constant load

n : Number of tensile bars

z : Coefficient in the range of 4. 8-9. 5

Sensitivity analysis of model variables, continuity sheet resistance of FRP-reinforced concrete beams in bending moment diagrams are shown below.

Oehlers Model

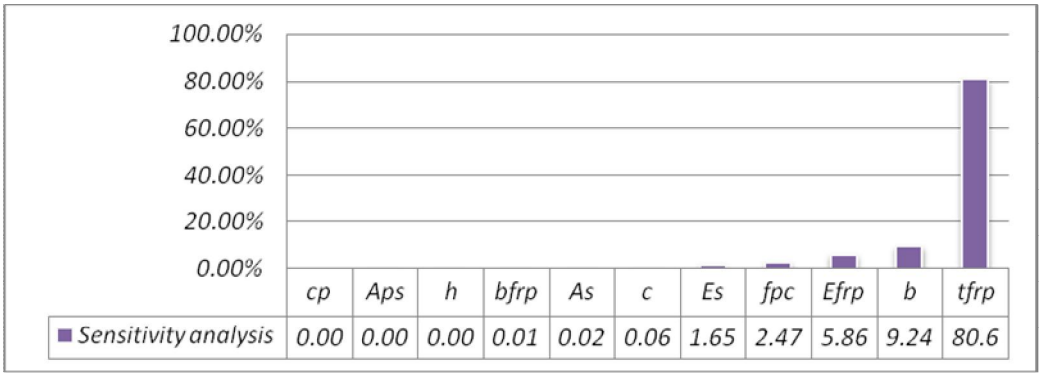


Chart 1: Sensitivity of the variables in the Ehlers model

Malek and Saadatmanesh Model

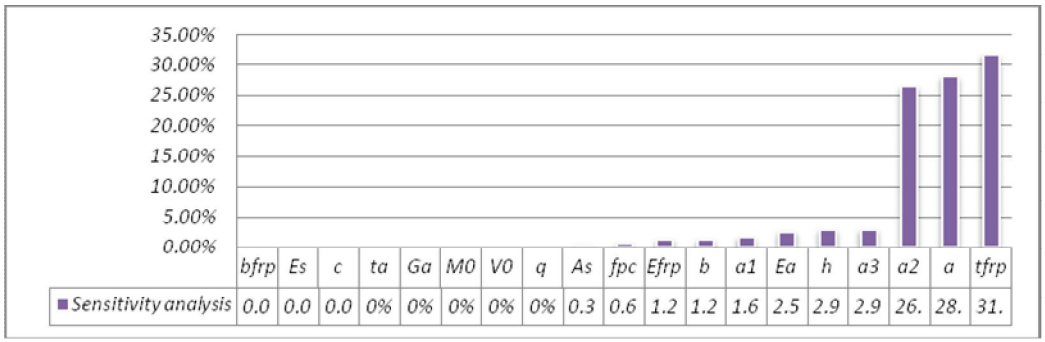


Chart 2: Sensitivity of the variables in Malek and Saadatmanesh model

Ahmed and Van Gemert Model

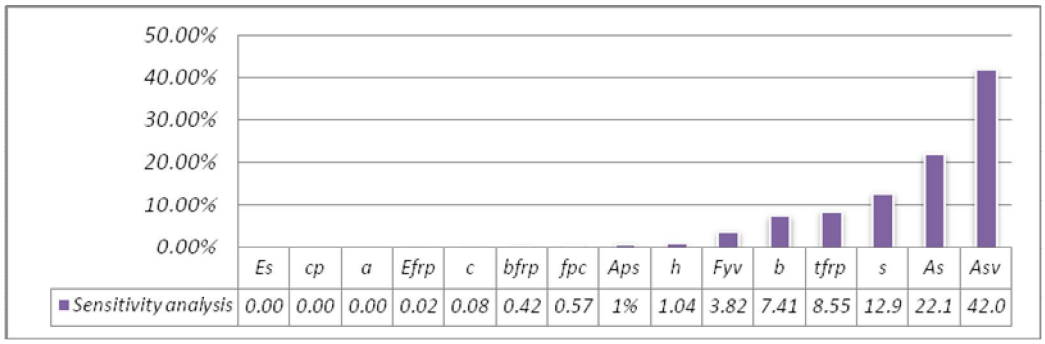


Chart 3: Sensitivity of the variables in Ahmed and Van Gemert Model

Ziraba et al. Model (model 1)

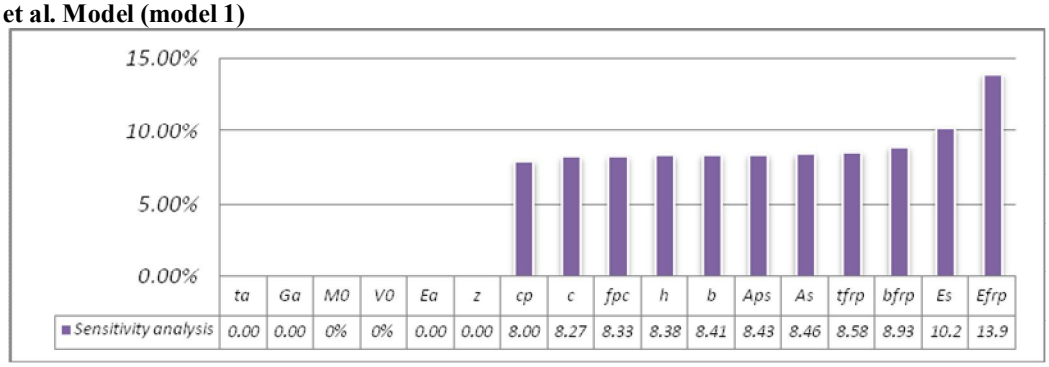


Chart 4: Percent of variables sensitivity in Ziraba et al. model (model 1)

Ziraba et al. Model (model 2)

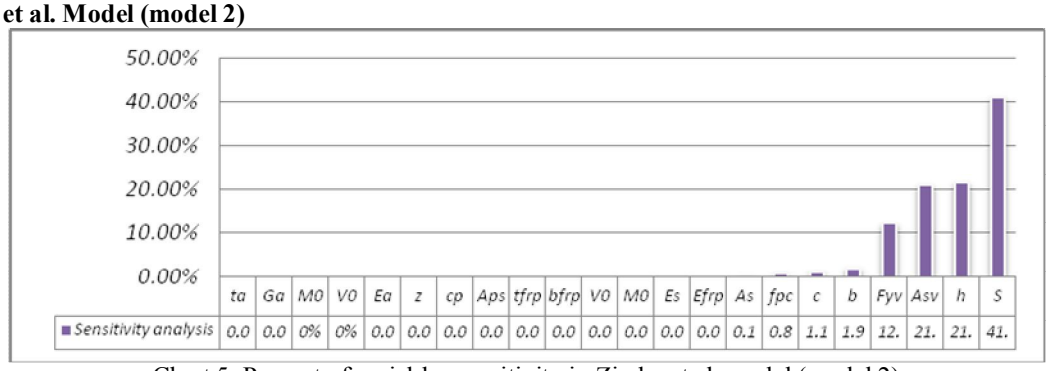


Chart 5: Percent of variables sensitivity in Ziraba et al. model (model 2)

Tomialan et al. Model

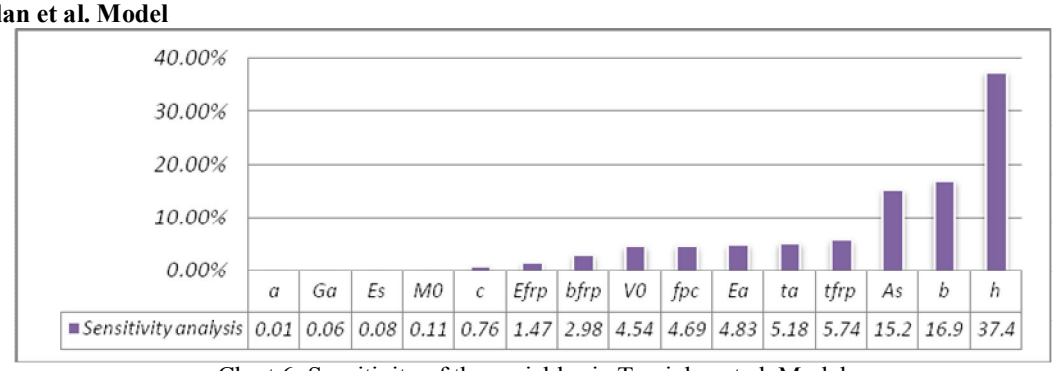


Chart 6: Sensitivity of the variables in Tomialan et al. Model

Raof and Hasanen Model (model 1)

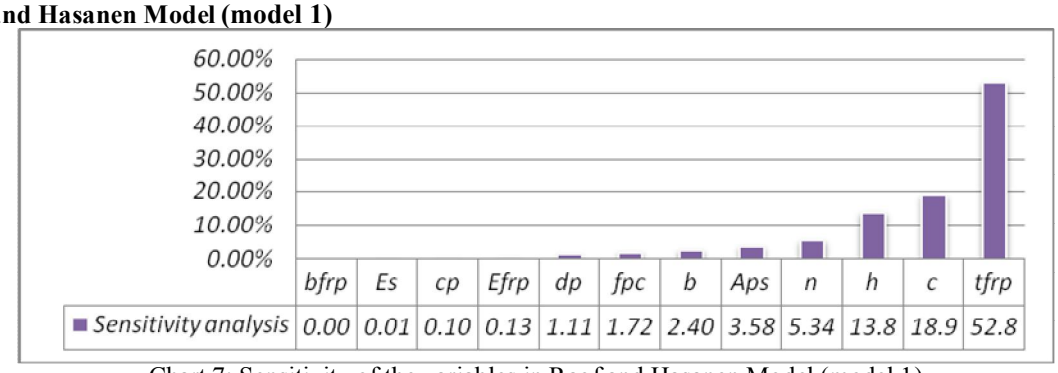


Chart 7: Sensitivity of the variables in Raof and Hasanen Model (model 1)

Raof and Hasanen Model (model 2)

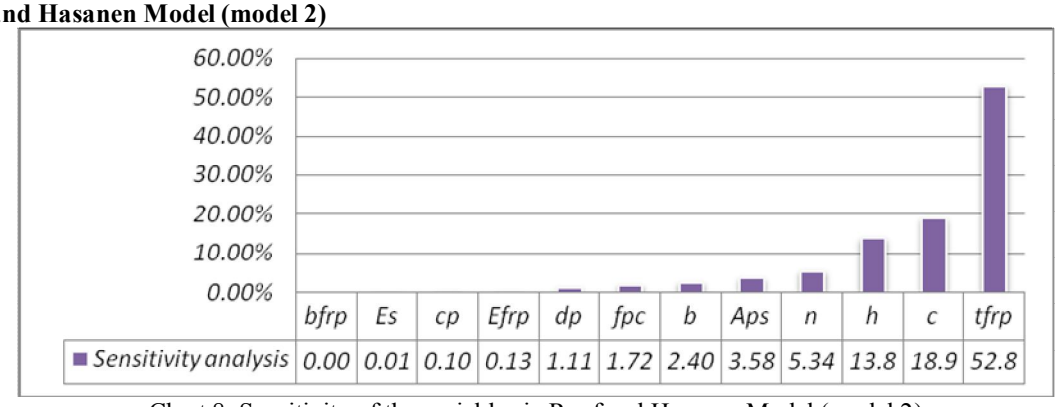


Chart 8: Sensitivity of the variables in Raof and Hasanen Model (model 2)

Wang and Ling Model

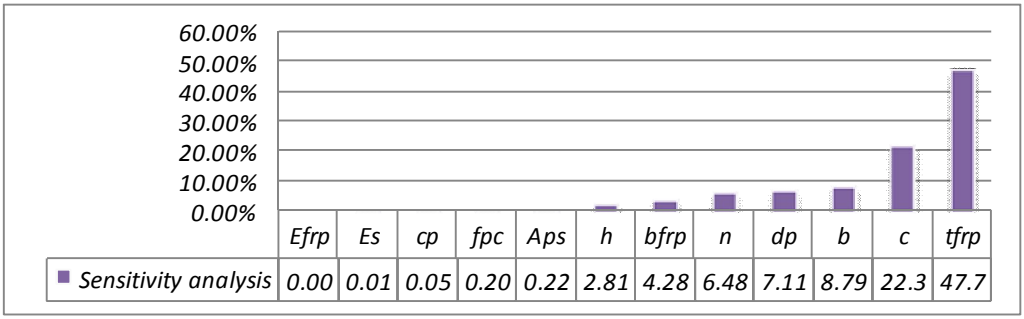


Chart 9: Sensitivity of the variables in Wang and Ling model

Hamelian and Varastehpour Model

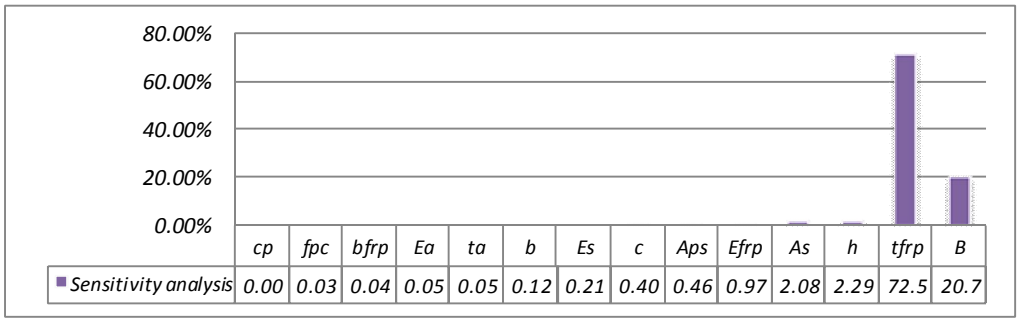


Chart 10: Sensitivity of the variables in Hamelian and Varastehpour Model

Conclusion:

Comparison of $f_c^{'}$, E_{frp}, E_s in separated plate models

According to the comparison of $f_c^{'}$, E_{frp}, E_s in the model in Figure 11, more sensitive models detachment pages mechanical properties of materials (steel rebar, frp panels and concrete) $f_c^{'}$, E_{frp}, E_s would be low and of the sensitivity of the modulus of elasticity of steel bars has the lowest, but $f_c^{'}$ that the compressive strength of concrete is low too. But, E_{frp} is related to the modulus of elasticity of *frp*, is higher than E_s and $f_c^{'}$.

Comparison of b **and** b_{frp} **in separated plate models**

According to the comparison of b and b_{fro} in the model in Figure 12, more sensitive variable representing the width of the beam is b in all models, separation pages of sensitive variables representing the width of the page is *frp*.

Comparison of b_{frp} and t_{frp} in separated plate models

Based on the comparison of b_{fro} **and** t_{fro} in the model in Figure 13, more sensitive variable representing the width of the beam is b in all models, separation pages of sensitive variables representing the width of the page is *frp*. All of the above models are the highest sensitivity of the model to account for the variable sensitivity of the Ehlers with t_{fro} variable 80. 60% of changes.

Comparison of *h* and *b* in separated plate models

According to the comparison of *h* **and** *b* in the model in figure 14, more sensitive variable representing the width of the beam is b in all models The models Hamilian, Malek and Zibara (2) and Raof (1 and 2) lower variable representing the height of the beam, but the sensitivity varied models Ahmad, Zibara (1), Wang, Ehlers and Tamilian more *h* variable.

Comparison of *c* and $c^{/}$ in separated plate models

The comparison between *c* and $c^{/}$ models detachment of the page in figure 15 is given, the sensitivity variable c representing the concrete cover in the area stretching in all models above the sensitivity variable $c^{/}$ representing the cover concrete

in the compression zone that is however in some models, there is no c' variable.

Comparison of A_s and A_s' in separated plate models

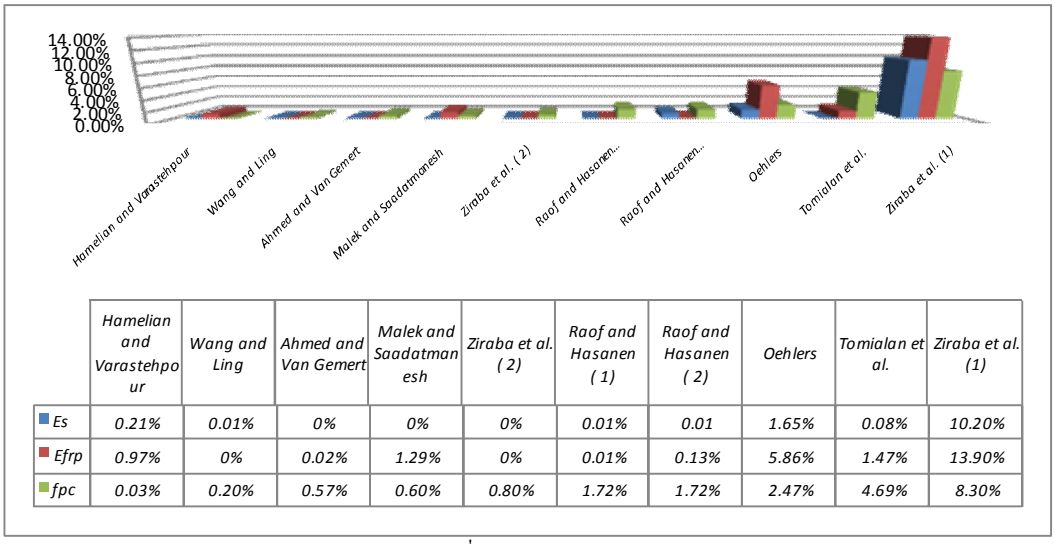
The A_s **and** A_s' compare the models in figure 16 are presented detached page, variable A_s, which represents the sensitivity of the cross section area of tensile reinforcement in all models. Higher sensitivity is variable A_s', which represents a cross-section of the reinforcement in the compression zone. However, in some models, there is no variable A_s'.

Maximum sensitivity of variables in separated plate models

The maximum sensitivity of the model of separation between the plates is given in figure 17. Most models that represent the variable susceptibility t_{frp} of *frp* thickness are higher than other models shows in themselves.

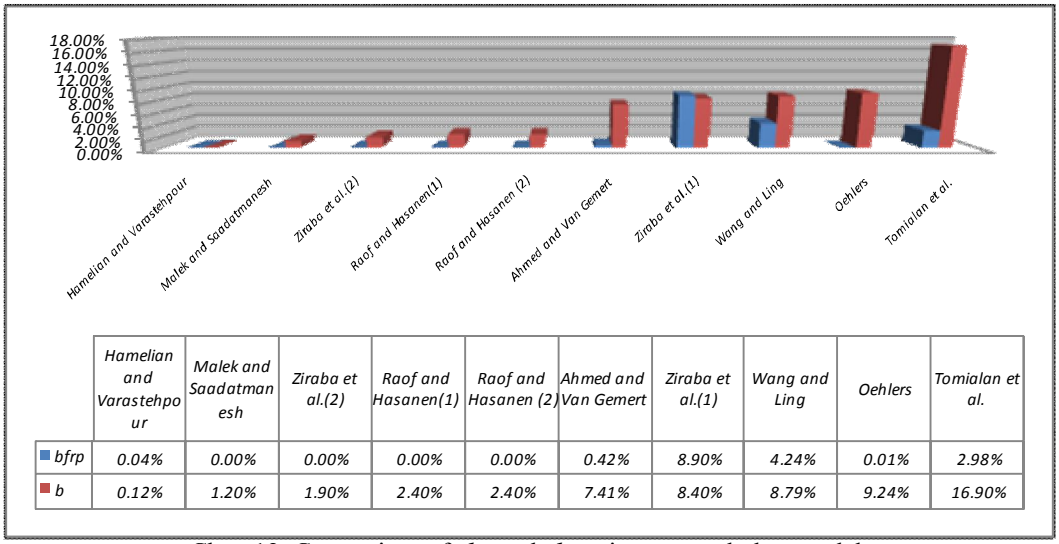
Acknowledgement

It's necessary to thanks from the faculty of Civil Engineering, Islamic Azad University, Yazd Branch, which this article was extracted from thesis of that faculty entitled "A continuous sheet resistance factors in FRP reinforced concrete beams in bending".



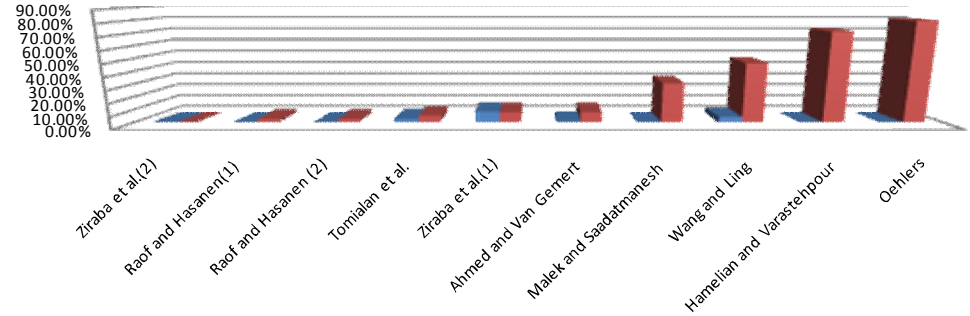
	Hamelian and Varastehpour	Wang and Ling	Ahmed and Van Gemert	Malek and Saadatmanesh	Ziraba et al. (2)	Raof and Hasanen (1)	Raof and Hasanen (2)	Oehlers	Tomialan et al.	Ziraba et al. (1)
Es	0.21%	0.01%	0%	0%	0%	0.01%	0.01	1.65%	0.08%	10.20%
Efrp	0.97%	0%	0.02%	1.29%	0%	0.01%	0.13%	5.86%	1.47%	13.90%
fpc	0.03%	0.20%	0.57%	0.60%	0.80%	1.72%	1.72%	2.47%	4.69%	8.30%

Chart 11: Comparison of f_c', E_{frp}, E_s in separated plate models



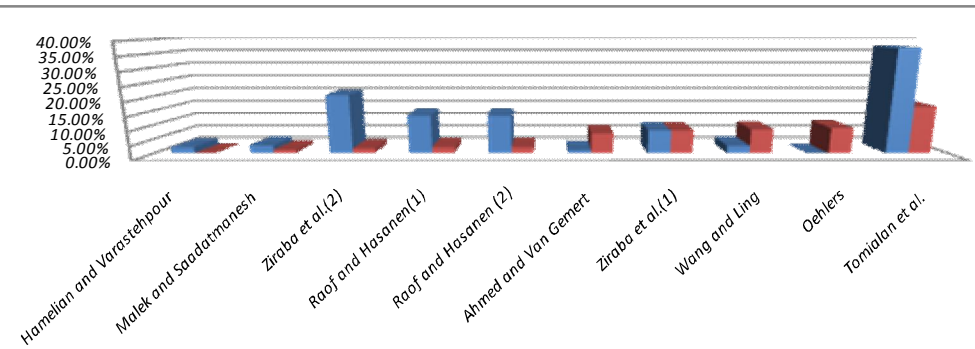
	Hamelian and Varastehpour	Malek and Saadatmanesh	Ziraba et al.(2)	Raof and Hasanen(1)	Raof and Hasanen (2)	Ahmed and Van Gemert	Ziraba et al.(1)	Wang and Ling	Oehlers	Tomialan et al.
bfrp	0.04%	0.00%	0.00%	0.00%	0.00%	0.42%	8.90%	4.24%	0.01%	2.98%
b	0.12%	1.20%	1.90%	2.40%	2.40%	7.41%	8.40%	8.79%	9.24%	16.90%

Chart 12: Comparison of b and b_{frp} in separated plate models



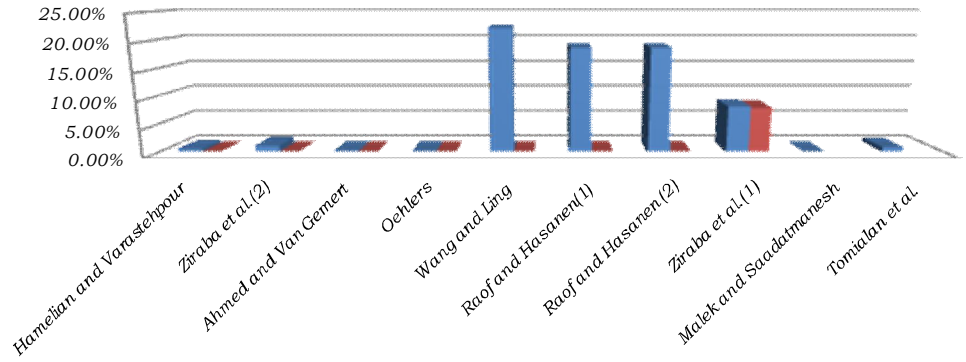
	Ziraba et al.(2)	Raof and Hasanen(1)	Raof and Hasanen (2)	Tomialan et al.	Ziraba et al.(1)	Ahmed and Van Gemert	Malek and Saadatmanesh	Wang and Ling	Hamelian and Varastehpour	Oehlers
bfrp	0.00%	0.00%	0.00%	2.98%	8.90%	0.42%	0.00%	4.28%	0.04%	0.01%
tfrp	0.00%	2.80%	2.80%	5.74%	8.50%	8.55%	31.72%	47.73%	72.58%	80.60%

Chart 13: Comparison of b_{frp} and t_{frp} in separated plate models



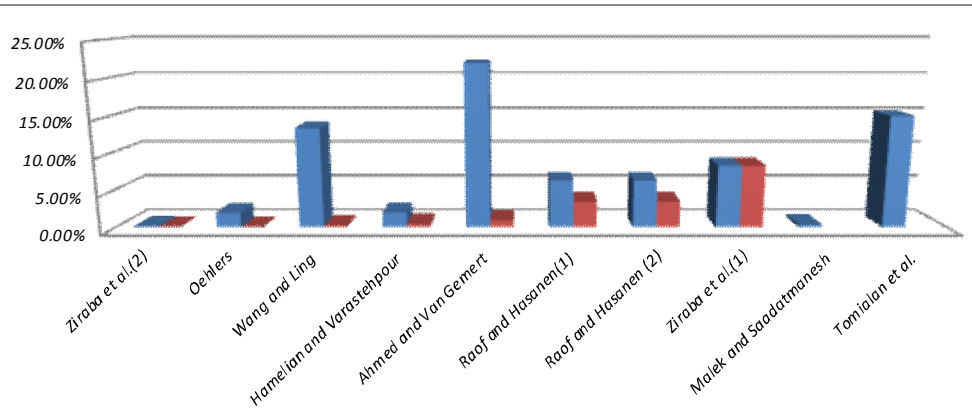
	Hamelian and Varastehpour	Malek and Saadatmanesh	Ziraba et al.(2)	Raof and Hasanen(1)	Raof and Hasanen (2)	Ahmed and Van Gemert	Ziraba et al.(1)	Wang and Ling	Oehlers	Tomialan et al.
h	2.29%	2.91%	21.00%	13.80%	13.80%	1.04%	8.38%	2.81%	0.00%	37.40%
b	0.12%	1.29%	1.90%	2.40%	2.40%	7.41%	8.41%	8.79%	9.24%	16.90%

Chart 14: Comparison of *h* and *b* in separated plate models



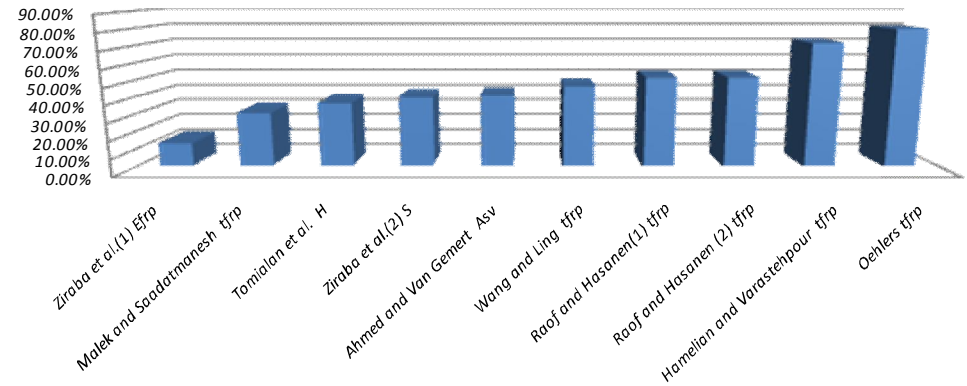
	Hamelian and Varastehpour	Ziraba et al.(2)	Ahmed and Van Gemert	Oehlers	Wang and Ling	Raof and Hasanen(1)	Raof and Hasanen (2)	Ziraba et al.(1)	Malek and Saadatmanesh	Tomialan et al.
c	0.40%	1.10%	0.08%	0.06%	22.32%	18.90%	18.90%	8.27%	0.00%	0.76%
cp	0.00%	0.00%	0.00%	0.00%	0.05%	0.10%	0.10%	8.00%		

Chart 15: Comparison of c and c' in separated plate models



	Ziraba et al.(2)	Oehlers	Wang and Ling	Hamelian and Varastehpour	Ahmed and Van Gemert	Raof and Hasanen(1)	Raof and Hasanen (2)	Ziraba et al.(1)	Malek and Saadatmanesh	Tomialan et al.
As	0.10%	2.00%	13.59%	2.08%	22.10%	6.44%	6.44%	8.46%	0.32%	15.20%
Aps	0.00%	0.00%	0.22%	0.46%	1.00%	3.58%	3.58%	8.43%		

Chart 16: Comparison of A_s and A_s' in separated plate models



	Ziraba et al.(1) Efrp	Malek and Saadatmanesh tfrp	Tomialan et al. H	Ziraba et al.(2) S	Ahmed and Van Gemert Asv	Wang and Ling tfrp	Raof and Hasanen(1) tfrp	Raof and Hasanen (2) tfrp	Hamelian and Varastehpour tfrp	Oehlers tfrp
Sensitivity analysis	13.90%	31.70%	37.40%	41.00%	42.00%	47.70%	52.80%	52.80%	72.58%	80.60%

Chart 17: Maximum sensitivity of variables in separated plate models

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