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A Study on Performance-Based Design Analysis for Vertical Extension of Apartment Units

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Abstract**—**There is no reinforcement example for the renovation of the vertical and horizontal extension to existing building structures which is a shear wall type in apartment units in Korea. Among these existing structures, the structures which are shear wall type are rare overseas, while Korea has many shear wall apartment units. Recently, in Korea, a few researchers are trying to confirm the possibility of the vertical extension in existing building with shear walls. This study evaluates the possibility of the renovation by applying performance-based seismic design to existing buildings with shear walls in the analysis phase of the structure. In addition, force-based seismic design, used by general structural engineers in Korea, is carried out to compare the amount of reinforcement of walls, which is a main component of wall structure. As a result, we suggest that performance-based design obtains more economical advantages than force-based seismic design.

Keywords**—**Vertical extension, performance-based design, renovation, shear wall structure, structural analysis.

I. Introduction

IN Korea, recently, the application of renovation by vertical extension, which is adding floors, to an old apartment units became an issue. This is because the Housing Act, which states that old apartment units can be extended on the horizontal orientation and to the vertical orientation from one-story to three-stories, was amended in 2012. In the case of cites which are suffering from overpopulation, the number of housing units with the vertical extension and the horizontal expansion are increasing as this form renovation increases the number of the apartment units and the horizontal expansion allows for the remodeling of an existing floor plan. The vertically renovated building can be more cost-effective than building new apartments. For these reasons, the vertical renovation of old apartment units has been a major issue.

Though the Housing Act was amended, there are a few questions about the implementation of the vertical renovation. Existing apartment units can be newly built in accordance with recent codes for structural design, if the building was completely demolished. The demand strength for past codes for the structural design to the vertical renovation is lower than the current codes for structural design. As a result, the structural performance of vertically renovated structures should be improved in order to meet the current codes for demanded for structure design. Also, the additional load of the building caused by the vertical extension should be distributed properly between the existing component and the new members. In addition to this, the vertical renovation should have the workability and economic efficiency due to the limitations of what can be changed, demolished, or reinforced. There are technological constraints, such as the lack of practical retrofitting techniques that are applicable.

In Korea, it is common to use force-based seismic design (FBD) in building structure design. This is because FBD is based on linear analysis as computation is simpler than nonlinear analysis. Nonlinear analysis takes a long time to compute due to the complicated procedures. While in FBD, the investment cost, time and labor is shorter than that of nonlinear analysis. FBD is the main method used to ensure life safety level of damage to property as a result of earthquake. This method has only one seismic performance objective in the design of apartments. Although the Korean Building Code (KBC) 2016 has been newly introduced, structural designers in Korea are mostly using the FBD method when designing buildings introduced from [1].

It is required to study whether performance-based seismic design (PBD) can be applied to improve the quality of construction and economical drawbacks that may arise due to various constraints of the vertical extension renovation of old apartment units. The FBD points out any of unnecessary aspect and constructive parts because it is aimed at life safety as the performance level of structures during an earthquake. But, in the PBD method, it points out specified members to reinforce. This is why by using PBD it is possible to reduce the number of reinforcement members. The PBD method sets various performance targets so that serviceability can be ensured for frequent small earthquakes. In addition to this, the PBD method aims at preventing collapse, even considering maximum earthquake force, which can be clearly reflected in the design, as well, as nonlinear analysis shows how much strength capacity is required. Therefore, PBD can be an appropriate method in the approach of renovation in the form of a vertical extension for old apartment units.

This study suggests a PBD method as an alternative method for the vertical extension renovation of aging apartment buildings in Korea. Story drift, compressive strain and story shear force were checked as the allowable criteria in the analysis by the PBD method These allowable criteria were referred to the tall buildings initiative 2011 (TBI) and the Los Angeles tall buildings structural design council (LATBSDC) 2011, as the criteria are not specified in KBC 2016 [2]-[4]. In order to compare the reinforced amount of the PBD method with that of the FBD method, a domestic building model was selected. Two programs for structural analysis, Perform 3D V5

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and Midas Gen 2017, which are commonly used in Korea, were used for the PBD method and the FBD method [5].

II. Performance-Based Design of Korea

The standard of Korean building structure for seismic design needs to be enacted. In Korea, the standard of seismic design for structures has been developed since 1988. It was inferred to be based on [6], and has been revised by [7], [8] since 2005. There are many interests for seismic design for buildings in the United States, and the evaluation of seismic performance for structures and the technique retrofitting structures have been developed in the country since the 1970s. The standard of Korean building structures for seismic design have been updated based on a variety of earthquake case studies of other countries because earthquake occurrence in Korea is less frequent and large earthquakes of high intensity are rarely observed. The guidelines for seismic design criteria for building structures have various criteria in the United States because of different information of geological hazards and geotechnical investigation on their site, while Korea does not [3], [4]. In Korea, most structural engineers have employed the FBD as an elastic design method because it is hard to predict and prevent various responses of building structures on varying earthquakes due to insufficient data of the geological investigation. The FBD can protect against damage to structures resulting from strong earthquakes. In FBD, the design coefficients in the linear analysis, such as the response modification factor, R, and the importance factor, I, are required, to consider the ductility of structural members and the nonlinear deformation of structures. It means that the FBD cannot provide predictable inelastic behavior in response to earthquakes shaking. The PBD introduced by [3], [4], targets securing the serviceability of buildings and considers the level of safety as collapse prevention against maximum earthquakes. The PBD shows changes in the strength capacity of members by elapsed time because the yielding mechanism of the structure is different on ductility. It means that the PBD can provide inelastic behavior in response to earthquakes shaking. Korean researchers refer to various case studies from numerous countries when considering the standard of Korean building structures for seismic design, as the country has limited data of actual earthquakes. In addition, as there are varying methods in the procedures of seismic design for structures in other countries, appropriately convergence of these for seismic design is important. Therefore, the KBC needs to be enacted to reflect nonlinear analysis of seismic design for building structures in relation to its site characteristics and type of structure.

Apartment units in Korea, which is are shear wall type, need criteria for allowable strength, story drift, and compressive strain for vertical and horizontal building expansion by adding additional floors, and extending floor slabs or adding balconies, terraces and mezzanines required the strengthening of the structure. The procedure of renovation requires plans for the modification of the existing structural frame or foundations prior to the implementation of the renovation. Studies on reinforced-concrete wall structures, which is a structural form that constitute a large portion of constructions in Korea, have been carried out, while studies on the enlargement of existing shear wall structures are at the beginning stage. The extension renovating of this shear wall structure should take into consideration the load increases including vertical expansion and horizontal expansion. As well, since the earthquake-proof criteria at the time of completion are different from the current standards, the question of how to establish the standards for securing the safety of the structure should be considered. Another reason is that most of the apartment units constructed with reinforced concrete shear wall structure have no resistance against the lateral force acting in the long side direction because the bearing walls are arranged in the short side direction. Therefore, it is necessary to establish a seismic performance evaluation method and PBD criterion in accordance with the characteristics of an apartment complex in Korea and vertical extension renovating condition.

This paper is carried out as a basic study to establish the PBD criteria for the renovation of the vertical and horizontal extensions of existing buildings as an example model that reflects the characteristics of the apartment units in Korea built in the 1990s.

III. Shear Wall Model Analysis

The model is a nine-story building of a shear wall type built in 1990. The model does not include underground floors. The renovation of a three-story vertical and horizontal expansion is carried out in this building model.

The existing walls have 18 MPa for compressive strength of concrete and 300 MPa for yielding strength of steel. The new walls have 24 MPa and 400 MPa for each. In case of linear analysis, Midas Gen 2017 - software most commonly used in Korea for structure design and structural analysis - is used. In Midas Gen 2017, the elastic modulus of concrete is 23,798 MPa for concrete of existing wall, and 25,791 MPa for the new walls. Poisson’s ratio of concrete is 0.167. The cyclic is considered as the degradation for the existing and new walls over time to nonlinear modeling by Perform-3D, which is a performance-based design software, as shown in the Fig. 2. The expected strength of material is 1.2 times for an existing wall and 1.1 times for a new wall. The concrete material model type is referred to as the Mander model and the steel material is referred to trilinear. The elastic modulus of concrete is $8500\sqrt[3]{f_{cu}}$ MPa, and the tensile strength of steel is 200,000 MPa. f_{cu} is the compressive strength of concrete, and the Poisson’s ratio of concrete is 0.15.

For the axial and bending layers, fiber cross section components are used. The ground floor has two layers divided by one-half the floor height for the each layer. The coupling beam is set as a dummy beam designed for the purpose of the load distribution of the upper load to the walls. For the effective stiffness, the wall flexural stiffness is 1.0 EI, the shear stiffness is 1.0 GAw, and the axis stiffness is 1.0 EAG, and the bending stiffness of the coupling beam is 0.2 EI, the shear stiffness is 1.0 GAw, and the axis is 1.0 EAg. The analytical results of the shear wall model have international guidelines of allowable criteria for the story drift, the shear force and the strain of the walls [3], [4].

As local zone factor, S is 0.22 and related to site characteristic. This analysis model is built on site class S_D. In S_D, F_a and F_v is 1.36 and 1.9. S_{DS} is 0.49867. S_{D1} is 0.2874. The importance factor is 1.2 and the response modification coefficient is 4. The overstrength factor and the deflection amplification factor of the system is 2.5 and 4.0, respectively. The allowable story drift is 0.015. As for Perform-3D, it is as follows [5], [9]. Site class is equal to Midas Gen 2017. Sa is 0.176. Importance factor is 1.2. The response modification factor is 1.0. Damping ratio is 0.025. Fundamental natural period and modal participation masses for the analysis model are investigated prior to seismic analysis of Perform-3D.

Fig. 3 shows that the design spectrum among seven-seismic waves. Seven seismic waves, generated by applying a single scaling factor for the seismic analysis in Perform-3D, were reflected in the analysis. This design response spectrum has a uniform hazard spectrum, and thus it has characteristics of response spectrum against earthquake with short period property and long period characteristic. It is difficult to find a record having the fitness for the full-period region of the response spectrum. When a single scaling factor is used, the size of the factor is usually about 0.3 to 3.0 times; however, in some cases, this figure may exceed 5 times. In the case of a single scale factor, the effect of higher order mode can be greater. Therefore, there is a limitation in applying a single scaling factor to ensure compatibility with the design spectrum. Seven seismic waves were chosen because the numerical relations on the coefficient for the modification of seismic scale are difficult to determine for the records of earthquake motion.

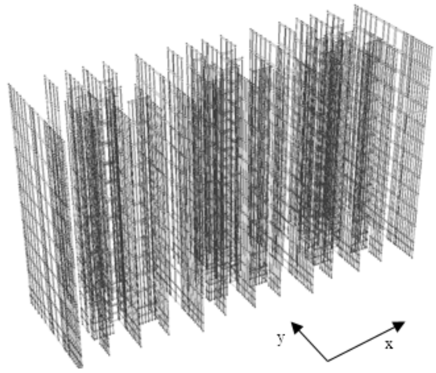
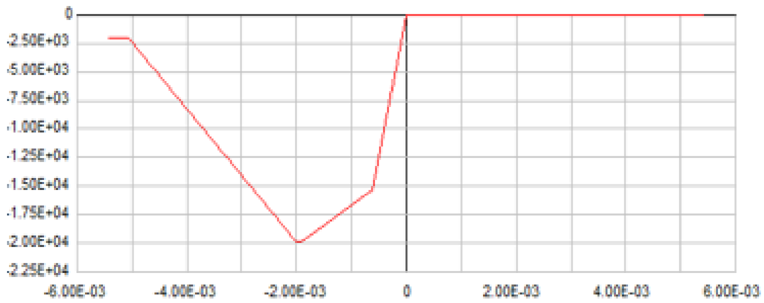


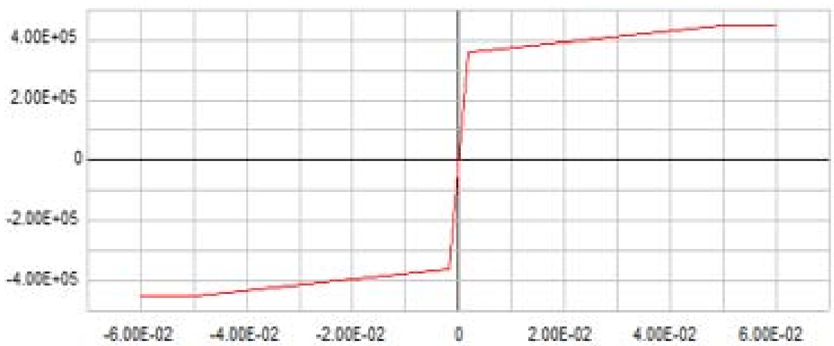
Fig. 1 Shear wall building model (Perform-3D)

TABLE I
COMPARISON OF PERIOD AND MODAL PARTICIPATION BETWEEN GEN 2017 AND PERFORM-3D

Type	Gen 2017	Perform-3D v5
First period	1.6099	1.6151
Second period	0.3868	0.4167
Modal participation of Mass on Tran-X	98.03	98.63
Modal participation of Mass on Tran-Y	93.97	94.59



(a) Concrete model (Mander model)



(b) Steel model

Fig. 2 Material model

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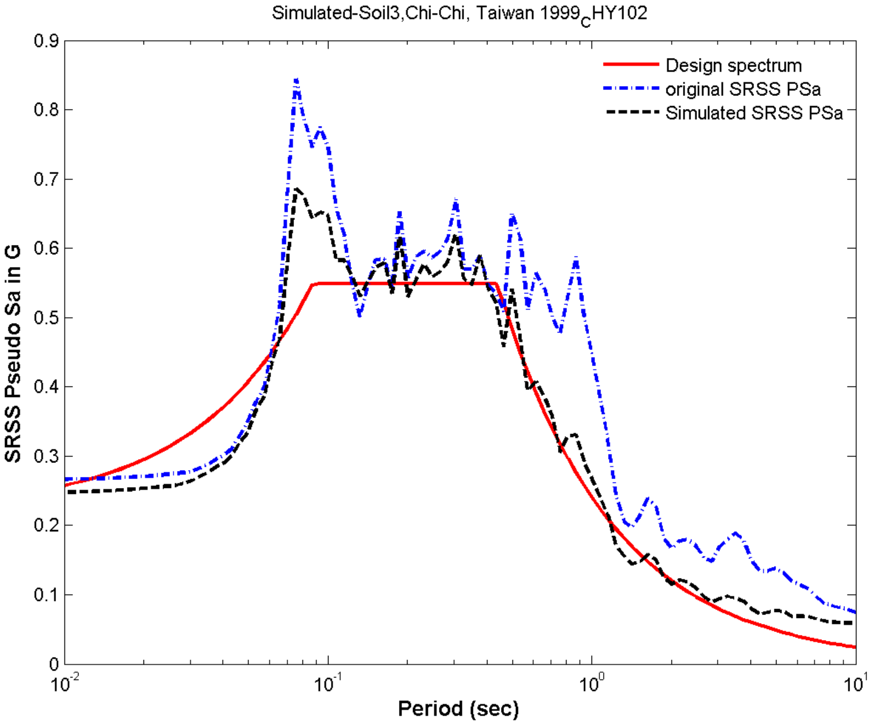


Fig. 3 Design spectrum on seismic wave applied in scale factor

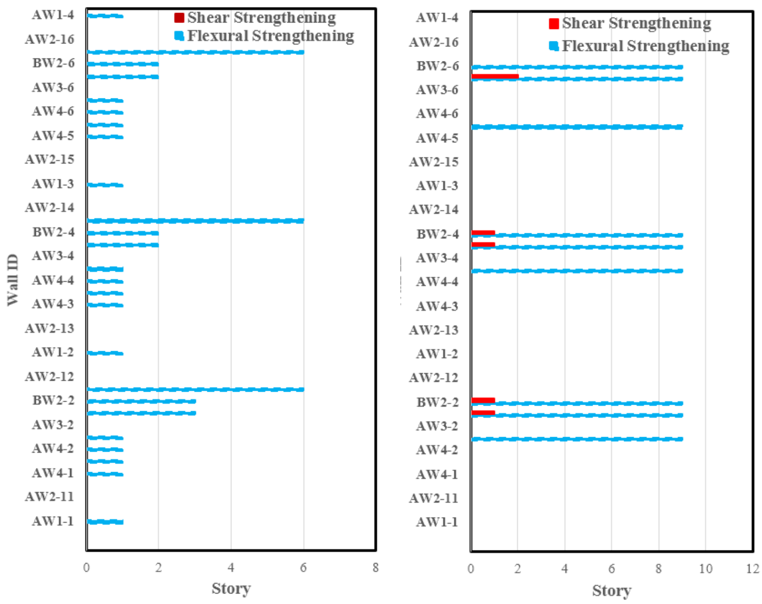
TABLE II
ACCEPTANCE CRITERIA

Type	Allowable value
Drift	1.5% (for mean of maximum response) 2.0% (on maximum response for each quakes)
Strain of concrete wall	0.2% (for mean of maximum response) 0.25% (on maximum response of each quakes)
Shear force of wall	$F_u \leq \Phi F_{n,e}$

IV. Analysis Result

The satisfaction of the acceptance criteria was confirmed by the wall, connection shear force and expected strength, as:

$$1.5F_u \leq \Phi F_{n,e} \quad (3)$$



(a) Performance-based design (b) Force-based design

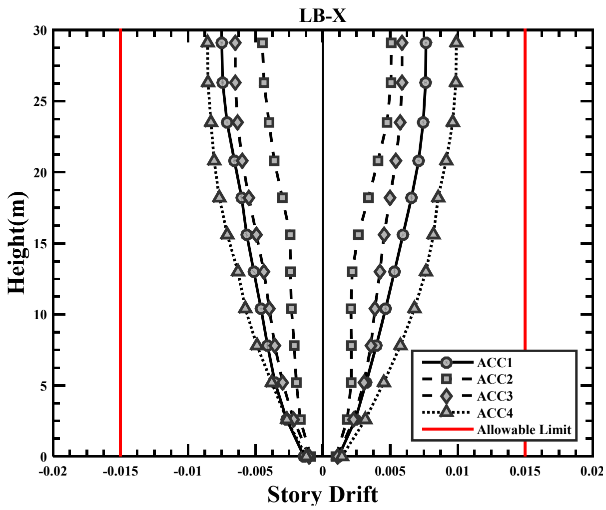
Fig. 4 The amount of reinforcement for renovation at PBD and FBD

As a result of the analysis, the shear force of the wall was required for reinforcement, and the reinforcement points of FBD and PBD were compared as shown in Fig. 4.

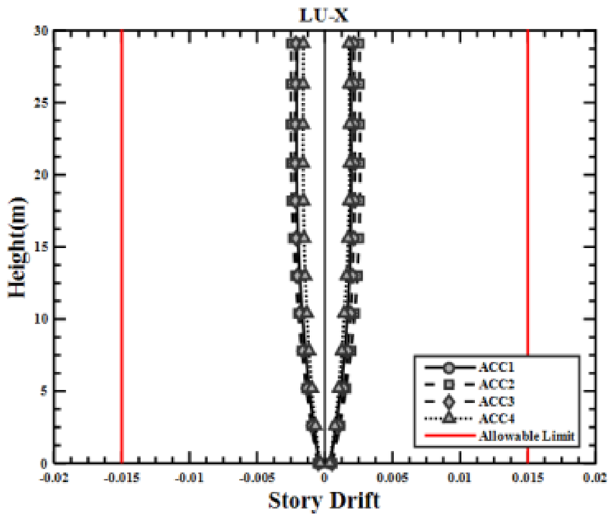
In guideline TBI, the maximum story drift should not exceed 4.5%, and the average story drift is limited to 3%. In the case of domestic shear wall type models, it is not as tall as high-rise buildings that adopt the guideline as is. Therefore, only 2/3 of this value was applied, so the average story drift was set at 2% instead of 3%.

The wall strain was less than 0.01, as Fig. 4 shows. The story Drift was limited to 1.5%. The maximum story drift in the x-axis direction was 0.01, and the maximum story drift in the y-axis direction was 0.005.

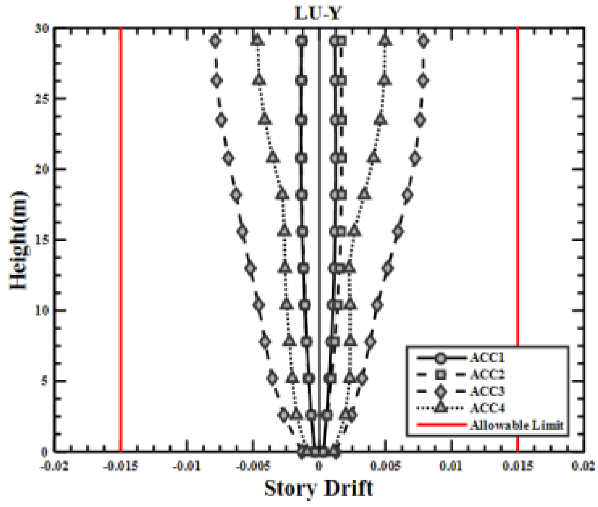
Analyzing the example model of an existing structure, shear reinforcement and flexural reinforcement are required to meet the allowable standard of shear force. In the case of FBD, shear reinforcement and flexural reinforcement are required, but the PBD results show that the reinforcement of the shear wall is not necessary.



(a) Story drift in wall ID-LB on X-axis

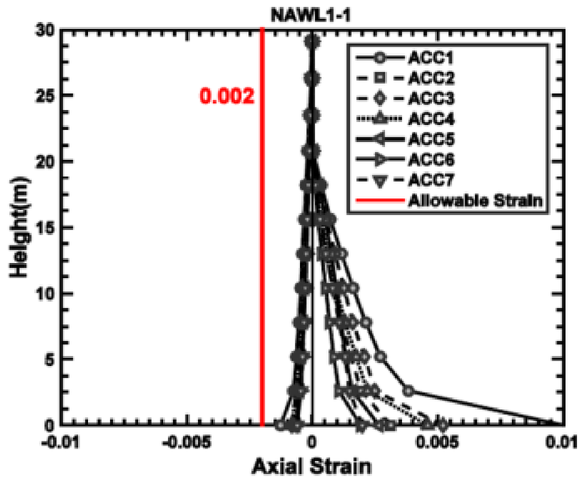


(b) Story drift in LU on X-axis

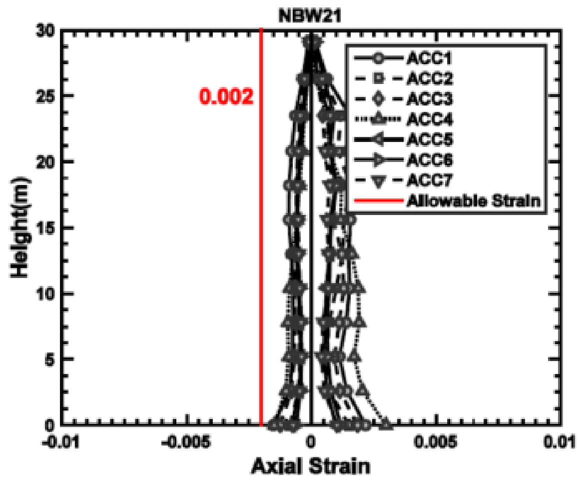


(c) Story drift in LU on Y-axis

Fig. 5 Story drift on height of walls



(a) Strain of NAWL1-1



(b) Strain of NBW21

Fig. 6 Strain distribution of wall on height

V. CONCLUSION

Walls and slabs have to be demolished in order to retrofit the shear reinforcement of existing structure expansion walls. During this demolition process, the rebar penetrates through the wall and is embedded in the foundation. As a result, this makes the renovation construction more complicated and limited. This simulated analysis showed a reduction of the construction cost by reducing the amount of both the shear reinforcement and the flexural reinforcement through the PBD than the existing FBD.

This is a basic study to improve a building system to enable the vertically addition of up to three floors in order to revitalize the project to the renovation of a vertical and horizontal of existing apartment units extension in Korea. It is confirmed that the reinforcement amount can be minimized by apply PBD in order to achieve structural safety for a three-story expansion and to reduce construction costs.

In the future, the effect of PBD should be clarified through various analysis including the type of layout, the rebar ratio of wall reinforcements and the aspect ratio of walls. Through this process, the PBD method could be applied to make a decision as to an alternative to securing the structural safety, construction and the economic efficiency of a project for the renovation in the form the vertical and horizontal extension of old apartment units in Korea.

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