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# Application of ACM Brace Retrofitting Countermeasure to Steel Structure

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**Abstract**

An advanced seismic retrofitting work for steel building structure with a doubtful seismic perfor-mance using ACM (Advanced Composite Material) bracing method, which consists of CFRP (Car-bon Fiber Reinforced Plastic) rod and steel sleeve, was proposed in this paper. In order to save a lot of residents' lives against a large-damaged earthquake, the retrofitting work using ACM bracing method to steel story building structure built by an old earthquake resistant design code was con-ducted. ACM bracing method was more economically and quickly applied to steel two-story build-ing structures in comparison with the steel K-shaped bracing method used as before. This kind of retrofitting countermeasure will lead to an extreme decrease in earthquake damages for the existing old steel building structures built by some old earthquake resistant design codes.


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*Keywords:* ACM brace; seismic retrofitting countermeasure; steel building structure.

## 1. Introduction

It is well known in Japan that a lot of reinforced concrete story buildings built by some old earthquake resistant design codes before 1981 were destroyed in the 1995 Hyogoken Nanbu Earthquake. Therefore, Japanese Government has adopted several significant politics concerning this issue since 1995 in order to reduce a lot of earthquake damages for RC and steel story building structures (referred to as S building) built before 1981 as quickly as possible. As some seismic retrofitting policies adopted by Japanese Government had been not carried out smoothly, Japanese

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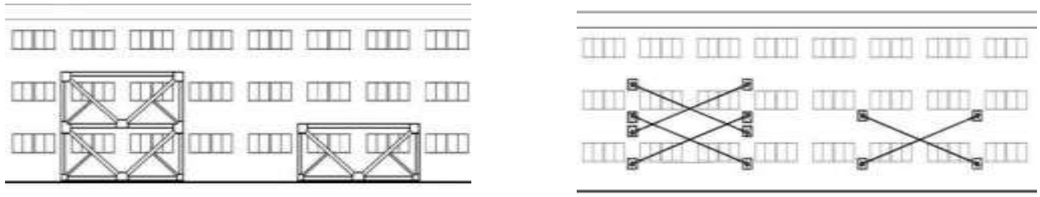
Government has been demanding a numerical target to quickly improve a seismic retrofitting ratio for all buildings by many local self-governments in Japan. This numerical target of seismic retrofitting ratio including RC and S buildings as well as wooden houses is 90% until 2017.

In general, a seismic retrofitting work for RC and S building structure using a typical steel brace requires not only a large amount of cost but also the residents' removal or temporary evacuation. It is more desirable and convenient for a lot of RC and S building owners that the seismic retrofitting work is conducted as quickly and economically as possible. It is therefore very important for structural engineer to propose a new retrofitting technique instead of X and K shape steel braces. At the present time, a seismic resistant performance of RC or S building structure is judged from a seismic index of structure, $I_s$, evaluated by some criteria established by the Japan building disaster prevention association (Housing Bureau in the Ministry of Land, Transport and Tourism in Japan 2001; Japanese Structural Engineer Association 2006). The number of steel brace required for the seismic retrofitting work of RC and S building structures can be decided to satisfy a given seismic judgment index value, $I_{so}$.

The author has already proposed a seismic retrofitting countermeasure for RC building structure using an advanced composite material (referred to as ACM) bracing method (Takatani 2008 and Takatani 2011), which consists of a carbon fiber reinforced plastic (referred to as CFRP) material, steel sleeves and anchors, in order to save a lot of residents' lives against a large-damaged earthquake. It is well known that CFRP material has several advantages of strong and light-weight feature, good durability, and wide applicability in comparison with the steel material. In this paper, ACM bracing method is applied for the seismic retrofitting work of S two-story building structure instead of steel bracing method.

## 2. Seismic Retrofitting Work using ACM Bracing

Heretofore, the steel bracing method has been used for the seismic retrofitting work of RC and S building structures in Japan. The steel brace as shown in Figure 1 (a) is used on the outside of RC building, and is usually done in the inside of structure. While, Figure 1(b) shows ACM brace installed on the outside of structure. It is more desirable and very important for a lot of RC building structure owners that an earthquake resistant reinforcement work for RC building structure can be conducted as quickly and economically as possible, and also can be done without residents' removal or temporary evacuation. The seismic retrofitting work conducted on the outside of RC building structure shown in Figure 1 may be more convenient for both the residents in RC buildings and their owners. It is, therefore, very important for structural engineer to propose a new seismic retrofitting technique instead of the steel brace technique under conditions with low cost and short construction period.



(a) Steel brace (b) ACM brace

Figure 1. Sketch for seismic retrofitting works using steel brace and ACM brace

ACM bracing method was proposed in order to aim at both low cost and short construction period in comparison with the steel bracing method. ACM bracing method consists of CFRP rod and CFRP sheet, steel sleeve, and steel anchor. Figure 2 shows ACM brace rod including CFRP rod and steel sleeve for ACM bracing method. The length 600mm of steel sleeve was decided from CFRP rod pull-out experiments from steel circular cylinder sleeve, and also can bear about 500 kN pull-out force. While, CFRP rods with various diameters are shown in Figure 3, and the material properties for CFRP rod is indicated in Table 1. The diameter of CFRP rod used for ACM bracing method is 10mm, and its tensile strength is 169.5 kN. Accordingly, three CFRP rods with 10mm diameter can bear about 500kN pull-out force. An advanced Epoxy resin developed by Konishi Co. Ltd. was employed for bonding between CFRP rods and steel cylinder sleeve (Horii 2007).

Figure 4 indicates steel anchors embedded in RC column, and the anchor diameter and length were decided from pull-out experiment under 500 kN shear force. Figure 5 shows steel cylinder sleeve and nuts for the ACM bracing, whose pull-out bearing capacity is about 500 kN Hisabe (2007). Also, the CFRP rod of the ACM bracing is shown in Figure 6, and the length of the CFRP rod is 500m required for ACM bracing method applied to RC 3-story building structure. Figure 7 indicates a CFRP sheet used to make a reinforcement of RC column against tensile force due to earthquake motions.

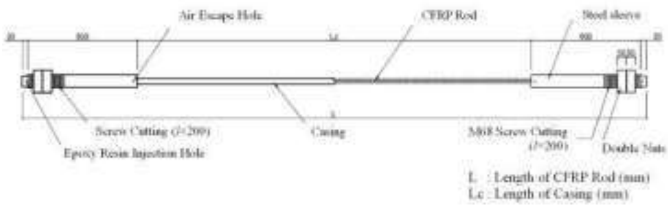



Figure 2. ACM brace using CFRP rod

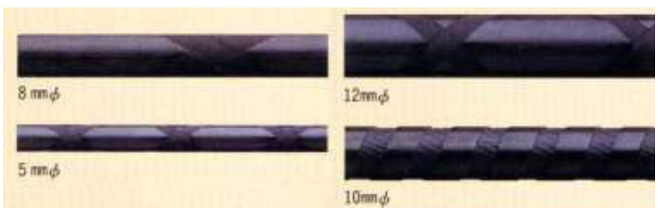



Figure 3. CFRP rod (Intended Type, Mitsubishi Plastics Co. Ltd.)

Figure 4. Anchors for ACM brace

Figure 5. Steel sleeves for ACM brace

Figure 6. CFRP rod (φ10mm, 5@100m)

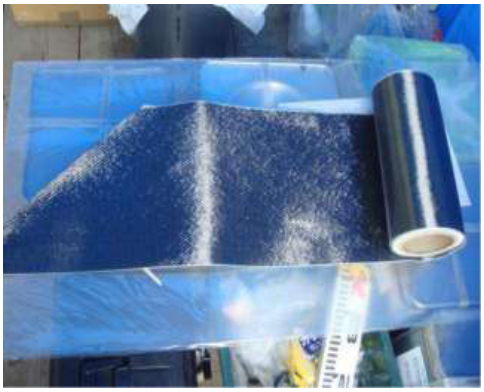
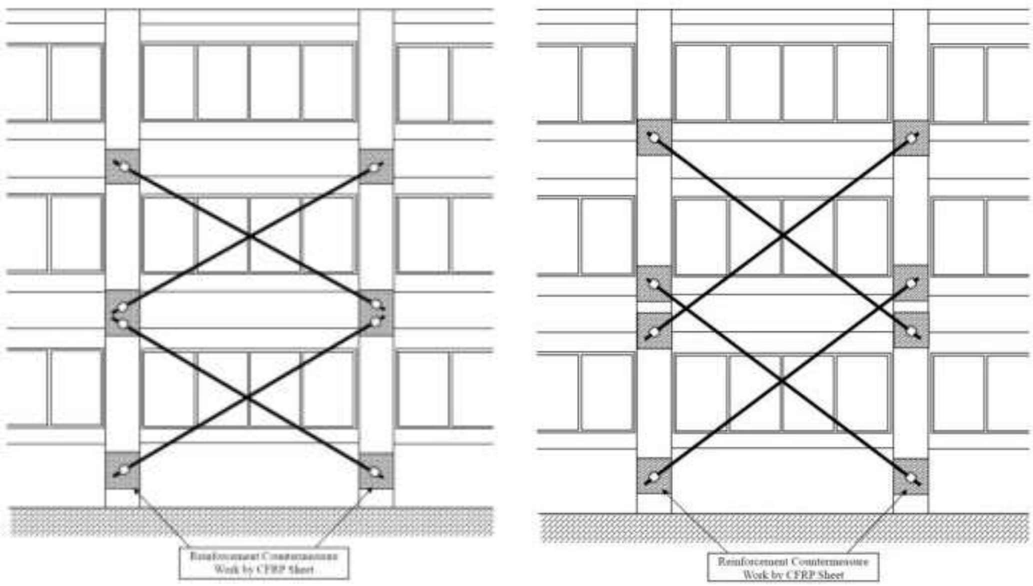


Figure 7. CFRP sheet for ACM brace

Table 1. CFRP material properties

| Diameter (mm) | 8 | 10 | 12 | 17 |
|---|---|---|---|---|
| Tensile Strength (kN) | 110.7 | 169.5 | 254.8 | 511.6 |
| Cross Section ($mm^2$) | 49.0 | 75.4 | 113.1 | 227.0 |
| Weight (g/m) | 78 | 119 | 178 | 360 |

RC column surface around an anchor was pasted and covered with four CFRP sheet layers with different directions taking into consideration a tensile force direction.




(a) Plan A (b) Plan B

Figure 8. Elevation view of RC building with the ACM brace

Figure 8 illustrates two typical elevations for the seismic retrofitting work using ACM bracing method. As the anchor embedment point in Plan A shown in Figure 8 (a) is located at the intersection area of RC column and beam where many reinforcing steel bars in RC column and beam gather around, it may be not so easy for a boring workman to make an anchor hole for ACM bracing method without cutting the reinforcing steel bars in this intersection area. Therefore, Plan B shown in Figure 8 (b) was proposed instead of Plan A, and the anchor embedment point avoids the intersection area of RC column and beam. In addition, it is found that the static deformation of RC building structure in Plan B is smaller than that in Plan A through the structural analyses for both Plan A and B. This is because that the rigid part around the intersection area of RC column and beam is usually assumed on the structural analysis. Conforming to custom on structural analysis, this rigid part around the intersection area is defined by the width of RC column or beam (Aoyama 1988).

Figure 9 indicates RC 3-story structure retrofitted by ACM braces (Takatani 2008 and Takatani 2011). After the installation of ACM brace, the steel anchor and sleeve were treated with a tarnish preventive. After this work, the steel cover was fixed on RC column surface as shown in Figure 9. After covering work of ACM brace, the final painting work was conducted and the covering box was made waterproof.

Figure 9. Completion of ACM braces

## 3. Application of ACM Brace to Steel Structure

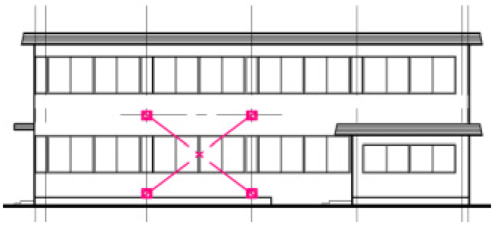
The seismic retrofitting work using ACM bracing method was conducted for S two-story structure shown in Figure 5. Figure 5 shows the floor plan and the elevation view of this S structure. The number of ACM brace is decided by the seismic index of structure, $I_s$, evaluated by some criteria established by the Japan building disaster prevention association in 2001 (Housing Bureau in the Ministry of Land, Transport and Tourism in Japan 2001). The seismic index of structure, $I_s$, must satisfy a given seismic judgment index value, $I_{so}$, of the seismic index of structure. In this case, the seismic judgment index value, $I_{so}$, is 0.7.

Table 2. Seismic index value $I_s$ of steel structure

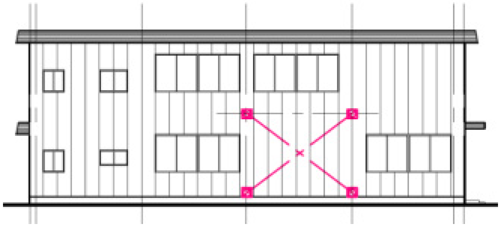
| Direction | Floor | Before ACM Installation | After ACM Installation |
|---|---|---|---|
| X | 2 | 0.68 | 0.68 |
| | 1 | 0.53 | 0.73 |
| Y | 2 | 0.73 | 0.73 |
| | 1 | 0.85 | 0.85 |

**Fisrt floor** **Second floor**

**(a) Floor plan (unit:mm)**



**East direction**



**West direction**

**(b) Elevation view**

Figure 10. Floor plan and elevation view

Table 2 shows the seismic index of structure, $I_s$, of the S building structure. It can be seen from Table 2 that the seismic index value of structure, $I_s$, of the first floor in X direction is less than the seismic judgment index value, $I_{so}$ =0.7, and the seismic index values of structure, $I_s$, in Y direction are more than $I_{so}$ =0.7. According to the seismic index values of structure, $I_s$, in “After Installation” in Table 2, ACM braces are located on the east side and the west one of this S structure.

Next, the construction process of this ACM bracing method is described. Figure 11 shows steel anchor fixed on steel column, and the anchor size was decided from pull-out experiment under 500kN shear force. Figure 12 indicates steel cylinder sleeves for ACM brace, whose pull-out bearing capacity is about 500kN and length is 600mm.

Figure 11. Anchors for ACM brace

Figure 12. Steel sleeves for ACM brace

Figure 12 shows a bracket fixed on steel column, and the steel column before ACM brace installation work is indicated in Figure 14. Figure 15 illustrates polishing work on the surface of steel column by a grinder before welding work of bracket. The welding work of bracket by a welder is shown in Figure 16. Figure 17 and 18 show a bracket fixed on steel column by the welding work. Figure 19 indicates steel anchor fixed on a bracket by the welding work.

Figure 13. Steel bracket for ACM brace

Figure 14. Steel column before ACM brace installation work

Figure 15. Polishing work on steel column before welding work of steel bracket

Figure 16. Welding work of steel bracket and a welder

Figure 17. Completion of welding work of steel bracket

Figure 18. Bracket after welding work

Figure 19. Steel anchor after welding work

Figure 20. CFRP rod cutting work

Figure 21. Steel sleeve with three CFRP rods

Figure 22. Steel sleeves before Epoxy resin Injection

Figure 23. Epoxy resin injection work into steel sleeves

Figure 20 indicates a cutting work of CRFP rod by a saw, and three CFRP rods are installed into each steel sleeve as shown in Figure 21. Figure 22 indicates steel sleeves before Epoxy resin injection work, and Epoxy resin injection work into steel sleeve is shown in Figure 23. Figure 24shows steel sleeves after Epoxy resin injection work.

Figure 25 indicates tightening work of sleeve-nut with a large screwdriver at the steel anchor. Both ends of ACM brace rod were fixed by four sleeve-nuts as shown in Figure 26 so that the tensile force of 10kN acts in the ACM brace. The shock absorbing rubber shown in Figure 27, which was newly developed by SRI Hybrid Co. Ltd., was used between the fixed anchor and the sleeve-nut.

Figure 24. Steel sleeves after Epoxy resin injection work

Figure 25. Tightening work of steel-nut with a screwdriver

Figure 26. Completion of tightening double steel sleeve nuts

Figure 27. Rubber ring for shock absorbing

Figure 28. Steel sleeve and bracket after anti-rust painting

Figure 29. Steel sleeve and bracket after finishing painting work


Figure 30. Completion of ACM brace installation

After the installation of ACM brace, the steel anchor and sleeve are treated with a tarnish preventive as shown in Figure 28 and 29. Photo 30 indicates the installation completion view of ACM brace fixed on S structure. It is found from this photo that ACM bracing method has a scenic view from the outside of the retrofitted structure because there is not much things to obstruct the view from the inside of the structure.

## 4. Concluding Remarks

In this paper, an advanced seismic retrofitting work for RC and S story building structures built by some old earthquake resistant design codes before 1981 was reported in order to save a lot of residents' lives against a large-damaged earthquake. ACM bracing method consists of CFRP rod, steel sleeve, and steel anchor. This ACM bracing method was applied to S two-story building structure in 2010. Materials in the seismic retrofitting work using ACM bracing method and the construction process of ACM brace were described in this paper.

The summary obtained in this paper is as follows.

(1) ACM brace retrofitting work has several construction advantages such as short construction period and low cost in comparison with the steel bracing method. Namely, ACM bracing method has a high cost performance.

(2) Although the installation work of steel braces requires a large construction machine of a crane-currying truck, the installation of ACM brace is not needed any large construction machine and also is effectively conducted under a safe operation.

(3) The construction work of ACM brace retrofitting countermeasure does not require a professional engineer or an expert.

This ACM bracing method may support a seismic retrofitting politics in the region where has a slightly delay in the seismic countermeasures, and can be a driving force to increase the safety of structures against a large earthquake and changes to a strong region against natural disasters. This kind of seismic retrofitting work for RC and S story building structures will lead to a decrease of earthquake damages in many countries.

## Acknowlegement

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