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Efficiency of bilinear and self-centering systems under along-wind load

*Hamidreza Alinejad[1)] and Thomas Kang[2)]

[1), 2)] *Department of Architecture & Architectural Engineering, Seoul National University, Seoul, Korea*
[2)] *tkang@snu.ac.kr*

ABSTRACT

Self-centering systems with flag-shaped hysteresis loops are very effective in absorbing energy and are well-known for their excellent characteristic to minimize residual deformations, which is very important for post-loading performance. Researchers widely investigated the behavior of these systems under seismic load. However, few studies focused on their performance under wind load. Several studies showed that damage accumulation of bilinear systems could be very significant because of the large mean component of along-wind load (Gani and Légeron, 2012). Bezabeh and Bitsuamlak (2020) revealed that self-centering systems could impressively reduce damage accumulation under along-wind load and showed that the value of reverse yielding strength has a significant role in the performance of these systems.

In this study, the behavior of bilinear and self-centering systems under along-wind load is investigated using single degree of freedom models and nonlinear time history analysis. The results confirm that self-centering systems could considerably reduce damage accumulation and have better performance than bilinear systems. It is shown that the optimum behavior of self-centering systems could be achieved where the reverse yielding strength is close to the standard deviation of the elastic force.

1. INTRODUCTION

Wind demand under extreme wind loads can be so large for tall buildings, resulting in difficulty for common elastic design. An alternative approach has been permitted recently to allow limited inelastic behavior in some elements to reduce design wind force (ASCE, 2019). For this reason, many studies are oriented to investigate inelastic behavior of structures subjected to wind load. Results of former studies revealed that damage accumulation of bilinear systems under along-wind load could be very significant (Gani and Légeron, 2012). Self-centering systems could effectively restrict damage accumulation under along-wind load due to the characteristics of their so-called flag-

[1)] PhD Student
[2)] Professor

shaped hysteresis (Bezabeh and Bitsuamlak, 2020). It was shown that the value of reverse yielding strength has a significant role in the performance of these systems.

The response of inelastic systems with bilinear and self-centering behavior was compared in this study, and the role of the reverse yielding strength in controlling damage accumulation was discussed. Expected behavior was evaluated for a case study building by single degree of freedom models and nonlinear time history analyses using forces obtained from wind tunnel test.

2. BILINEAR & SELF-CENTERING SYSTEMS SUBJECT TO ALONG-WIND LOAD

Because the mean component of along-wind load is large, full hysteresis cycles are not formed in bilinear systems. After first yielding, plastic deformation increases till the moment the load reduces, and the system reaches the first elastic shakedown state (pure elastic behavior). The state would be changed if the load exceeds yield strength, resulting in further plastic deformation until the next moment that load decreases again, and the system reaches the second shakedown state. Plastic deformation accumulates under this process until the system reaches the last elastic shakedown after the peak load.

The behavior of self-centering systems strongly depends on the value of reverse yielding strength. If it is very large, amplitudes of unloading stages can be smaller than reverse yielding. Consequently, the response of system would be very similar to conventional plastic systems. However, if it is very small, the system undergoes cyclic behavior even under very small load fluctuation, which may raise a concern for low-cycle fatigue failure. The optimized value of reverse yielding strength can be determined based on the relation between response of elastic and inelastic systems. In response to the same load, the magnitude of unloading stage in elastic and inelastic systems is similar. In this condition, response of inelastic system is linear cyclic about the value of the mean component with an effective amplitude in order of standard deviation of elastic force, σ_{Fe}, until the load exceeds the yield strength. Thus, it can be expected that self-centering systems with reverse yielding strength equal or close to σ_{Fe} move back toward the original state in the unloading stage, rather than remaining in the elastic shakedown state, and effectively reduce damage accumulation.

3. CASE STUDY

In this study, behavior of bilinear and self-centering systems was evaluated for a case study building using single degree of freedom (SDOF) models and time history analysis with the following assumptions. The building has a height of 120 m, a square shape plan with a width of 40 m, total mass of 384×10^5 kg, natural frequency of 0.38 Hz, and damping ratio of 1.2%. It is located in an urban area with wind speed profile power of 1/4. Generalized mass, stiffness, and damping for the first mode were calculated by assuming a linear mode shape and used for SDOF models.

Open-access wind tunnel test database of Tokyo Polytechnic University (Tamura, 2012) was used to extract aerodynamic load for a model with similar exposure, aspect ratio, and angle of attack of zero. Wind speed (10-minute average) at building height (V_H) in the range of 40 to 75 m/s was considered, and accordingly, velocity scale and time scale were calculated. Generalized force was obtained by dividing overturning moment in along-wind direction by building height and scaled up for each wind speed. Then, a set of 1000 random time history with length of 10 minutes and time increment of 0.05 sec was generated for each value of wind speed using PSD of the scaled force (Shinozuka and Deodatis, 1991). Yield strength (F_y) was defined as the maximum aerodynamic force to avoid instability, large deformation, and full reduction of the resonant component. Three cases of 0.0, 0.1K, and 0.2K were assumed for post-yield stiffnesses (K_{py}), where K is initial stiffness. Several cases were set for reverse yield strength (F_{yr}) of self-centering systems, including 0.25σ_{Fe}, 0.50σ_{Fe}, 0.75σ_{Fe}, 1.00σ_{Fe}, 0.50F_y, 0.75F_y, and 1.00F_y, where σ_{Fe} is the standard deviation of elastic force obtained from the results of the elastic analysis for each case.

Force-displacement curves of the inelastic systems are shown in Fig. 1. As expected, the results clearly illustrate that the self-centering system with $F_{yr} = \sigma_{Fe}$ can effectively reduce the maximum displacement, whereas behavior of system with $F_{yr} = F_y$ is almost the same as bilinear system. Also, system with $F_{yr} = 0.25\sigma_{Fe}$ cannot control damage accumulation desirably.

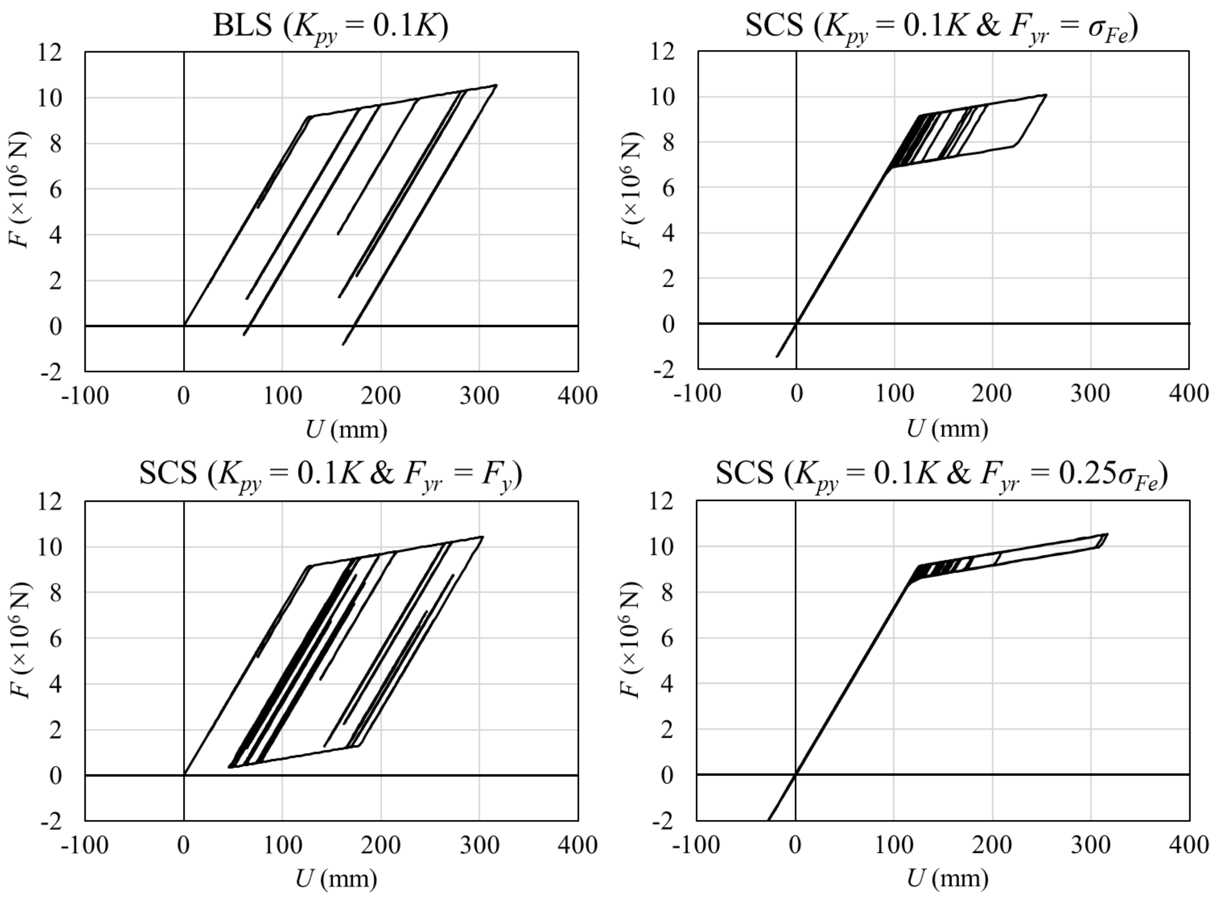

Fig. 1 Responses of bilinear and self-centering systems to along-wind load

Fig. 2 shows the ensemble average of maximum displacement of self-centering systems with respect to F_{yr} for different values of V_H and K_{py}. It can be seen that the maximum displacement of systems with $F_{yr} = \sigma_{Fe}$ is the minimum in all conditions and is larger for systems with smaller or larger values of F_{yr}. Based on the results, the responses of systems with F_{yr} in the range of σ_{Fe} and $0.50F_y$ are comparable.

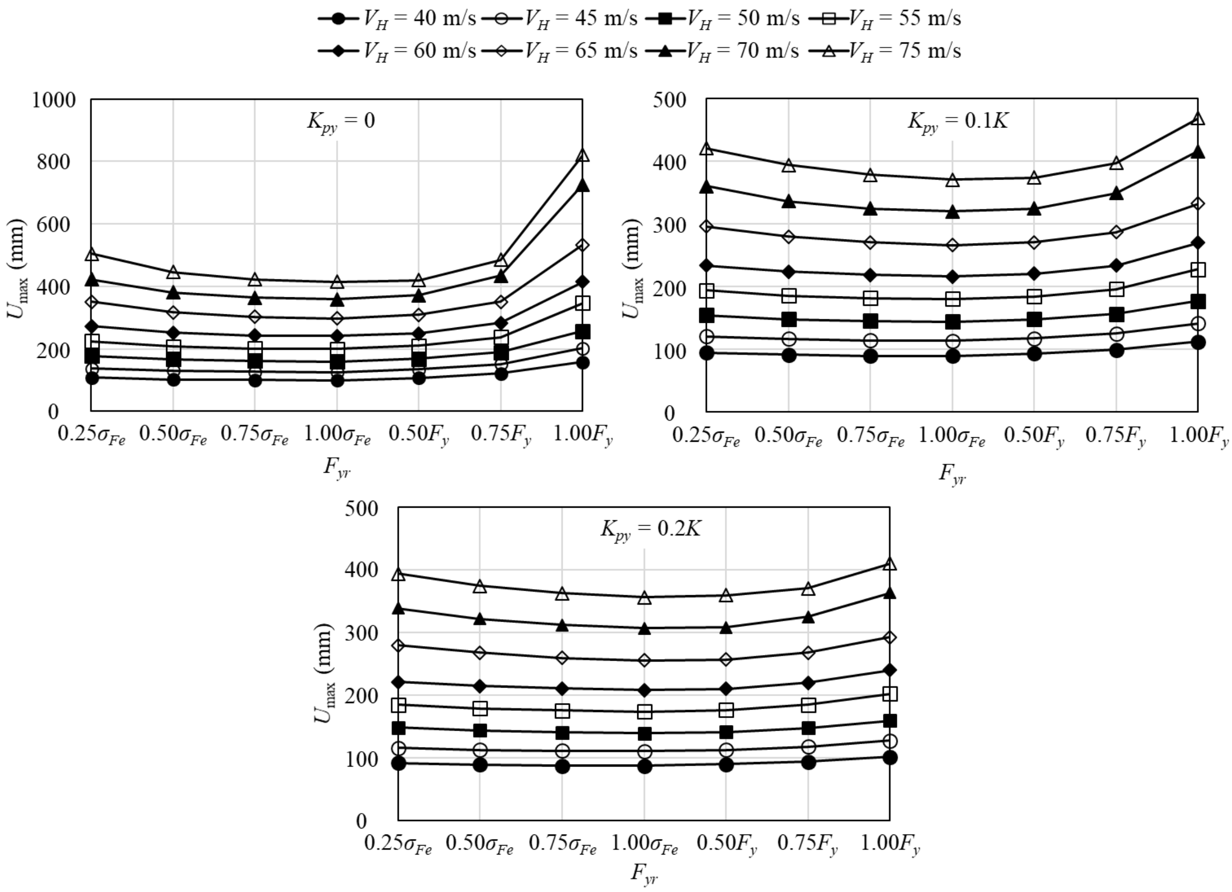

Fig. 2 Relation between maximum displacement and value of reverse yield strength

4. CONCLUSIONS

In this study, responses of inelastic systems with bilinear and self-centering under along-wind load were evaluated using wind tunnel test results and nonlinear time history analyses. Based on results, self-centering systems can efficiently control damage accumulation and their maximum displacement is considerably smaller than bilinear systems. Also, the difference between maximum displacement of two systems is more significant for higher wind speeds. It was found that efficiency of self-centering systems strongly depends on reverse yield strength. According to the results, self-centering systems have the highest efficiency if the reverse yield strength is between standard deviation of elastic response force and half of yield strength.

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