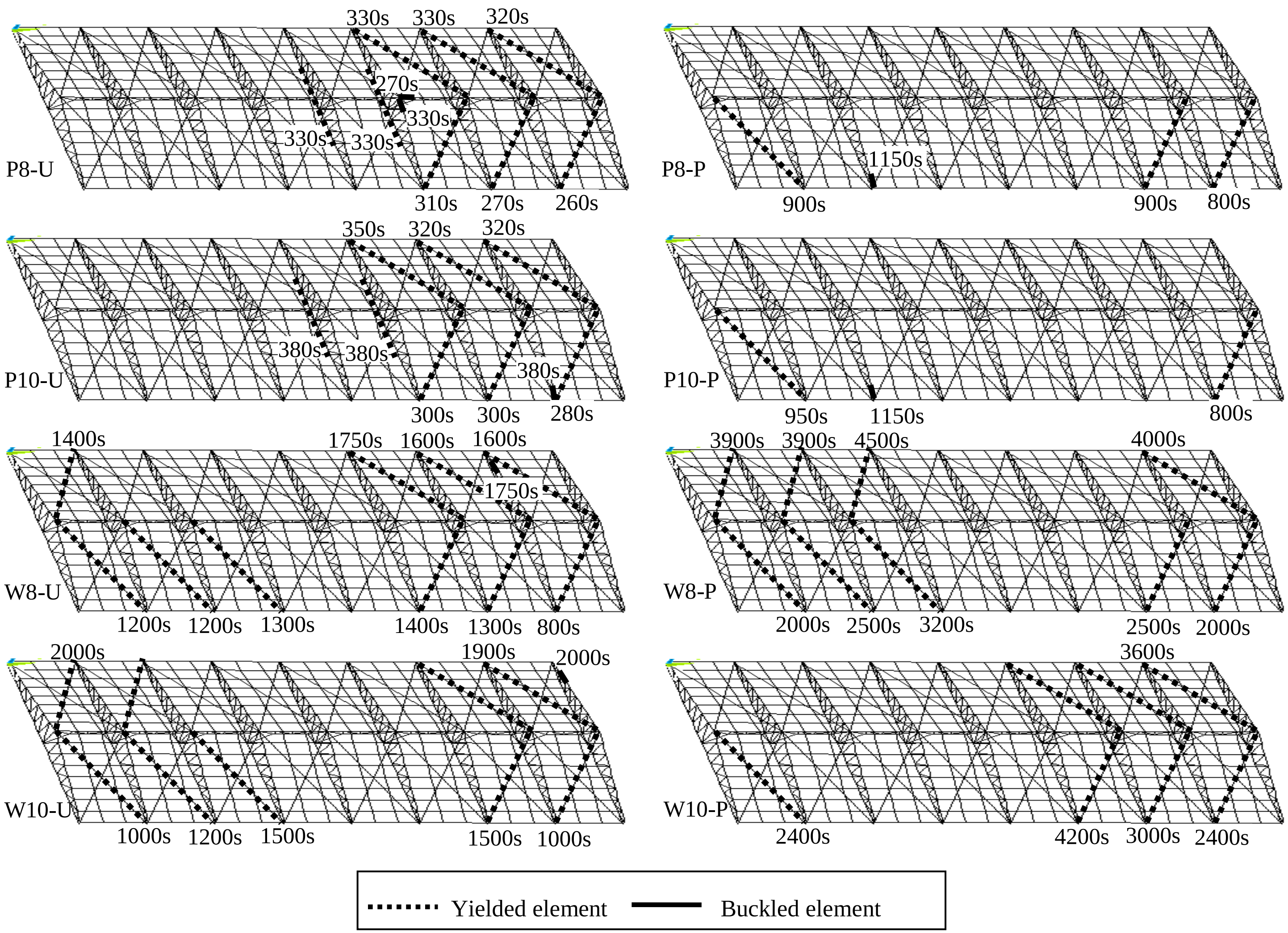

Figure 7. The Sequence of Failure for the Structural Member

The high temperature gradients between the upper and lower frame members induce higher tension in the bottom chords and higher compression in the top chords. The expansion of the roof structure in the longitudinal direction causes the main roof frames to sway horizontally with respect to their supports. This results in additional torsion, shear and moments due to the second-order (P-Δ) effect. The situation can be illustrated in Figure 9. In particular, the combination of the increasing force, the deteriorating mechanical properties and the P-Δ effects causes some of the top chord members to fail in flexural buckling as shown in Figure 7. The failure of these members essentially indicates the failure of the structural system as shown in Figure 10.

The results obtained from the various fire scenarios can be summarized in Table 4. Based on the simulation results, it is found that the fuel type and fire protection of steel roof members significantly affect the time to failure. The scenarios in which the wood fuels are used and the roof members are protected yield considerably longer time to failure compared with the cases in which the plastic fuels are used and the steel is unprotected. The clearance height of the roof structure and the location of the ignition source are considered supplementary factors to the structural failure time. The 10-m clearance height slightly extends the failure time because of a slower feedback of heat from the burning contents. It should also be noted that for the plastic burning scenarios the failure time of the structural system with fire protection is significantly lower than the 1-hour fire resistance period as determined by the ASTM E 119 standard test.

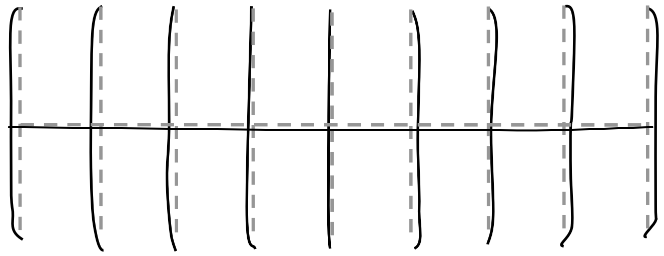

Figure 8. Longitudinal and Transverse Thermal Expansions of the Roof Structure for Case P8-P

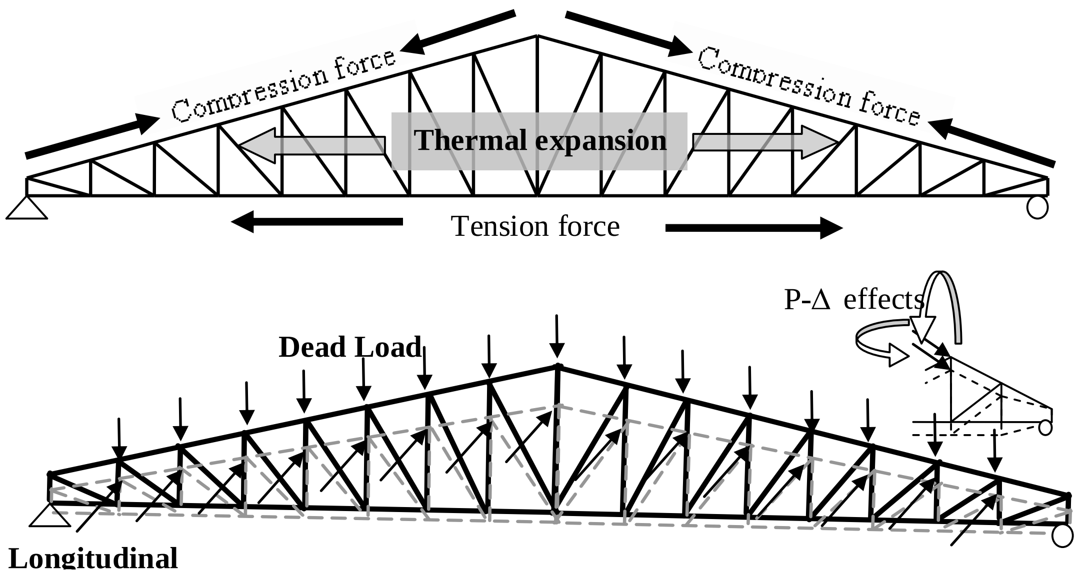

Figure 9. High-temperature Effects upon the Main Roof Frame

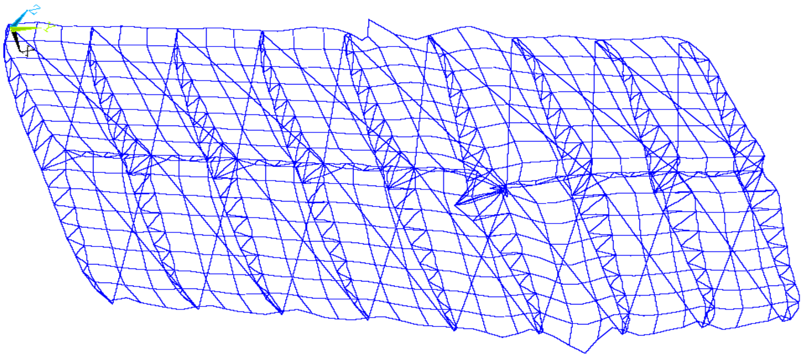

Figure 10. Failure of the Structural System

Table 4. Summary of Structural Failure Time

Case	Failure Time (second)	Maximum Temperature in Structural Members (°C)
P8-U	330	639
P8-P	1150	292
P10-U	380	639
P10-P	1150	275
W8-U	1,750	561
W8-P	>7200	565
W10-U	2,000	561
W10-P	>7200	521

Conclusions

Various fire scenarios are simulated in the current study to investigate the behavior of the steel roof structure of a typical warehouse. The fuel type (wood or plastic) and the clearance height (8 m or 10 m) of the roof structure are taken as the varying parameters. The different fire scenarios are modeled using the FDS program and the behavior of the steel roof frames is examined through a series of nonlinear finite element analyses. Based on the fire modeling results, it is found that the fuel type significantly affects the behavior of the modeled fire in terms of the fire growth and the spread of flames. The plastic contents result in a rapid fire growth due to the significant feedback of heat from the flames. The wood contents result in a considerably slower fire growth that occurs through direct radiation from the flames to nearby objects. Furthermore, the clearance height of the roof is found to have slight effects on the fire behavior.

Through the use of the simulation study, various aspects of the structural behavior under fire are observed. The failure of the roof structure is due to three key factors: the increasing axial force in tension and compression due to thermal expansion; the significant drop of the mechanical properties of steel due to the increasing temperature; and the P-Δ effects from the movements of the structure. In addition, the failure time of the roof structure depends upon the fuel type and whether or not the roof members are protected from fire. The highest risk is found for the cases of plastic storage contents without fire protection for the steel roof frame members. Note that, comparing with the investigated safe egress time or the failure time of the structure, the fire resistance of the fire protection based on ASTM E 119 may not be conservative for plastic contents.

It should, however, be noted that even though the proposed approach may be used as a framework for fire risk assessment of steel structures in accordance with the fire safety regulations. Further studies should be conducted to verify the assumptions adopted as well as to overcome the limitations of the proposed procedure.

Acknowledgement

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