Multi-Damage State Design of Steel Moment-Resisting Frame retrofitted with Minimal Disturbance Arm damper

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1. Introduction

This abstract summaries a design procedure for retrofit system, installed on steel moment resisting frame (MRF) with beam composite section, which deals with multiple performance levels. The design procedure includes four performance levels, three for the frame retrofitting and one for the frame recovering, after a strong seismic event. The adopted retrofit system, for the multi-phase design, is the minimal disturbance arm damper (MDAD), it reduces the damage at the bottom flange of the beam under positive bending, which is larger in beams fully constrained by floor slab.

2. Multi-phase Design Concept

Figure 1 top, shows the three proposed phases of the retrofit design: (a) elastic phase; (b) plastic phase; (c) post fracture phase;

Each phase aims to improve the frame behavior differently.

Figure 1 bottom, identifies the recovering phase, designed to recover the frame capacity after a strong seismic event: (d) recovering phase.

Phase A, considers the elastic response of the frame. The target is the delay of the beam yielding, by reducing the positive moment at the beam ends. Phase B considers the formation of the plastic hinges at beam ends. The target is to reduce the positive plastic rotation, in order to delay the occurrence of fracture. Phase C, considers the frame behavior after the beam fracture occurred. The target is to avoid the frame capacity reduction and to maintain the maximum strength until a target drift.

The performance objectives of the experimental work on a half scaled two spans MRF, retrofitted with MDAD, are: phase A, 15% positive beam moment reduction, at 0.75% drift; phase B, 20% positive beam plastic rotation reduction, at 3.0% drift; phase C, 0% frame capacity reduction after fracture, at 3.5% drift; phase D, frame capacity recovering above 80% of the maximum value, at 4% drift.

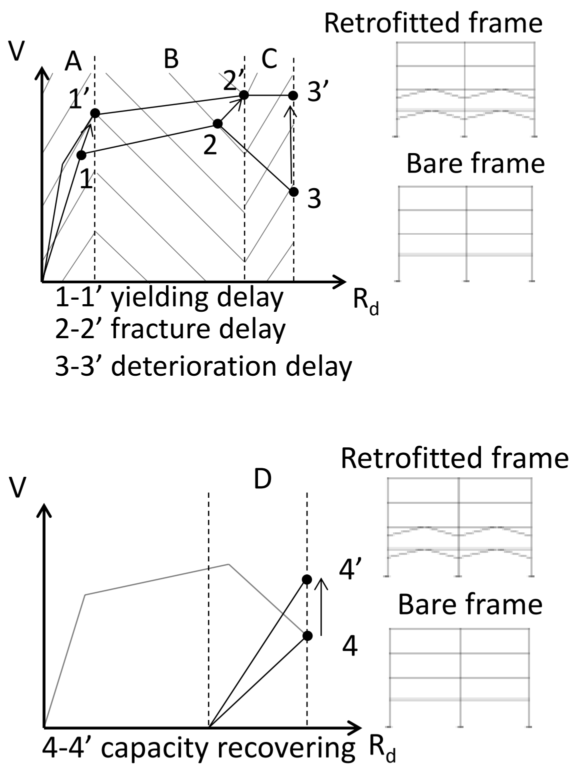

Fig. 1. Top: bare vs retrofitted capacity curves;
Bottom: capacity recovering curve

3. Experimental validation

The specimen shown in Figure 2, is a half-scaled multi-span substructure extracted from the second story of a Japanese four-story, two-span, steel moment-resisting frame. The test specimen is composed of three HSS-175×175×12 columns and two H-200×100×5.5×8 beams. The length of the specimen is approximately 6 m, and the high 1.65 m.

The results of the experimental work show a reduction of the positive beam moment, during phase A, of 15% to 20%, at 0.75% drift. During phase B, the positive plastic rotations at the beam ends reduced of 15% to 20%, until 3% drift, when fracture occurred at the bottom flange of internal beam end. At the cycle of fracture, no capacity reduction was detected. The recovering phase D, used stronger MDAD to compensate the beam fracture. The new configuration, at 4% drift, was able to recover the frame capacity up to 94% of the maximum value, while the bare frame capacity decreased to 64% percent.

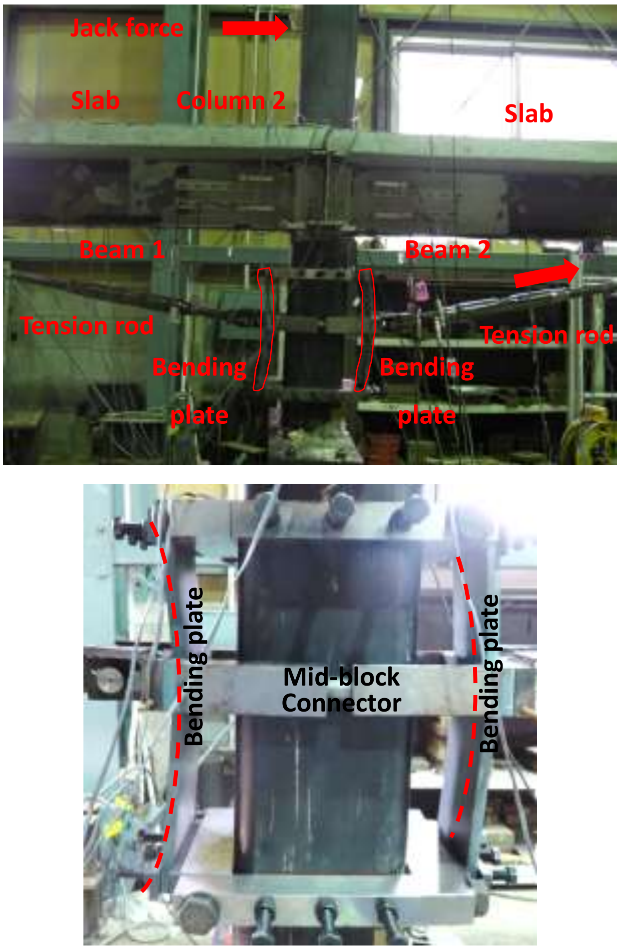

Fig. 2. Top: Specimen front view; Bottom: MDAD details

The elastic stiffness of the retrofitted frame increased by 15%, less than a tolerance of 20%. The yielding force increased by 15% as expected in design. In the plastic range, the secondary stiffness increases by 46%, thanks to the delay of the yielding of each single beam end. The maximum force achieved in the retrofitted frame was 320 kN, 28% greater than the bare frame maximum value. The frame capacity decreased by 6% and 21%, during the first and second 3.5% cycles, respectively. The local damage, such as concreate cracks and bottom flange compression force, were reduced by the MDAD, which significantly improved the composite section effect and avoided the reduction of the negative plastic moment of the beam, due to local buckling.

Table 1: Bare and retrofitted frame results comparison

	Bare	Retrofit	ratio
Elastic stiffness [kN/mm]	9.6	11.0	1.15
Yielding force [kN]	119	136	1.14
Secondary stiffness [kN/mm]	5.0	7.3	1.46
Max. force [kN]	250	320	1.28
Post-EQ stiffness [kN/mm]	7.3	9.0	1.23
Post-EQ force [kN]	160	250	1.56

4. Conclusions

The multi-phase approach was proposed and verified through experimental investigation. The MDAD could improve the frame performance for each design level, reducing the positive moment and plastic rotations at the beam ends, for phase A and B. It avoided the frame capacity reduction after fracture occurred, in phase C. During phase D, The stronger MDAD recovered the frame capacity to 96%, under multiple fractures.

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