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Application of Precast System Buildings with Using Connection of Unbonded Post-tension and Local Dissipater Device

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Abstract

A precast connection concept, which is equivalent in ability but is more efficient compared to that of the isolation concept, was developed by Precast Seismic Structural System (PRESSS) in USA. This kind of connection uses the unbonded post-tension system and a replaceable dissipater device. The unbonded post-tension works to restore structural deformation back to its initial position after excitation caused by earthquakes, and the dissipater device acts like a replaceable fuse when the earthquake design load is exceeded. This concept was adopted to ACI 318 Code since 2002, NZS 3101:2006, and also in Indonesian Standard, SNI 7833-2012. The research,development, and application of this concept were carried out in Indonesia in 2013 – 2014, using local materials and an alternative sustainable earthquake precast system through the service life of the building.

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*Keywords:*Earthquake-resistant sustainable building, capacity design concept, PRESSS, unbonded post-tension connection, replaceable dissipater device, local material and method;

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The new Indonesian earthquake code followsthe new philosophy in earthquake resistant buildings which leads to a performance base design, this is due to public resistance to the classical capacity design concept. Major earthquakes,such as Loma Prieta (1989) and Northridge (1994) in California and in New Zealand (2010-2011) showed that buildings designed with capacity design concept behaved as expected. The death toll was small, but the damage interupted business in the building since repairment took a long time, high cost and was difficult to carry out. The community protested the use of the capacity design concept and urged the engineers to find a better design concept.

This paper discusses the concept of earthquake-resistant building technologybased on the precast method (PRESSS)as a "one stop solution" against the new Earthquake Building Code. This paper covers the history and technology concept of PRESSS and theresearch, development, and implementation of the method in Indonesia.

Nomenclature

P	Force
P_o	Design force
P_y	Yield force
P_{max}	Maximum force
Ω	overstrength facfor P_{max}/P_o
f_2	added strength P_{max}/P_y
Δ	Displacement
Δ_y	Yield displacement
Δ_{max}	Maximum displacement

1.1. Background

Earthquake resistant building design in the American Code has been improving since the occurrences of major earthquakes, such as the San Francisco Earthquake in 1910. In early stages, the dilemma that occurred was the determination of the seismic force design,that should be determined so as to minimize the damage or to determine a smaller load level that results in a cheaper design, but one that could experience severe damage due to a major earthquake.

In the period of 1960-1980, two important concepts in the design of earthquake resistant buildings were developed, namely, the seismic design hazard concept and capacity design concept. Earthquakes are considered as a random phenomenon, so it can be described by statistical tools, the probability theory can then be used for decision making.

In New Zealand, the capacity design concept was developed by three leading experts, i.e.,Paulay, Park, and Priestley [9].In principle,structures could be designed to be ductile and posses adequate strength despite experiencing large deformations. The structure may not experience damage in the case of a minor earthquake and may experience significant damage wihout experincing failure in the case of a major earthquake (long return period).

In the case of a major earthquake, the structure should perform a beam mechanism collapse. Earthquake design forces were taken as maximum earthquake forces, reducing by a factor that depends on the specified level of structural ductility. Damage to the structure is set to occur in certain places that do not leadto the total collapse of the building.The damage of the frame structure should occur in the beam and column base (called the plastic hinge). Plastic hinges should be specifically detailed to be able to dissipate seismic energy. The capacity design concept was then adopted by the United States, mainly because of its pragmatic design strategy. The use of smaller seismic forces, coupled with special detailing to prevent fatalities, is a strategy that meets the principles of reliability and economy.

The capacity design concept was then widely spread worldwide, after being adopted in the United States (1972), except in Japan. Japan is a developed country that has many cities with buildings and a dense population, and is located in an area that frequently experiences major earthquakes. The capacity design concept,which permits the damage if a major earthquake happens,seems to be unattractive to the Japanese because it will lead to the interruption of business and the repair would be take a long time and be expensive. The Japanese fanatically adopted the elastic concept, i.e.; the building should not be damaged even if it is hit by a major earthquake. A typical strategy, that developed in Japan, is to "avoid" the earthquake force to enter the construction by providing base isolation and damping systems[2,4].

The capacity design concept was thoroughly tested by Loma Prieta Earthquake (1989) andNorthridge Earthquake (1994) in California. The death toll was small, but damages to buildingsweresevere,causing bussiness interruption.The repair work tooka very long time, wereat large cost, and were sometimes difficult to implement. Architectural damageswere not simple issues as well. Damagewas directly proportional to the rate of deformations of buildings, which up to that time was not taking into consideration in the Code, which is based on the capacity design concept. Society then demanded the engineers to think of a better sustain concepts but one that is still economical in the first investment.

The first response of the engineering community after the two earthquakes was to introduce a structural performance criteria in classicforce-based design methods. The performance requirement is a drift limitation, consisting of serviceability of drift level to avoid architetural damage and ultimate drift level to avoid total failure. Another response from the engineering community was to develop performance-based design concepts, which in the details is a displacement-based design method. Performance-based design is actually an attractive alternative, but the calculations and the detailing require advanced understanding of the structure in the inelastic condition.This case causes slow implementation among engineers.

In terms of earthquake-resistant building technology, there emerges some alternatives, thatin essence, tries to control the deformation of the structure.The technology provides base insulation and damping systems (passive, active, or tune mass damping). The technology requires devices generally produced by industries with high technological materials and methods which are expensive. The application of this technology on the structure also requires advanced understanding of the theory of inelastic structural dynamics, an aspect not properly socialized among engineers.

Earthquake-resistant building technology based on precast concrete with a dry joint system made of prestressed unbounded post-tension and a dissipater device, was developed exclusively by America and Japan (1994-2002), known as the PRESSS Technology (Precast Seismic Structural System). This technology is capable of providing a performance that is equivalent to the performance provided by basic insulation and damping technology. The technology uses equipment that can be produced locally at low cost. Thedesign methodhas alreadybeen standardized, andincluded in stand-alone sections in major building codes. Currently in Indonesia, there are quite a lot of companies that can do precasting work. So this technology could potentially developed to anticipate a new earthquake building code.

1.2. The history of PRESSS technology

PRESSS technology deals with precast concrete system, which is known as a systemwith intrinsic advantagesin the speed of construction, has a better quality, and is economic compared with the conventional system. The system is growing rapidly in the United States, the Netherlands, Italy, Finland, the Mediterranean countries, and Eastern Europe. The use of precast concrete systems in earthquake areas was very limited until the end of 1990's in the absence of a rational and flexible provision in the major building code, and often because of a lack of knowledge and confidence about its performance in the earthquake area[7]. In the previous approaches, which are typically known as monolithic emulation, precast components connected with cast in place (wetjoin) technique significantly reduces the advantages of precast construction.

In the 1990s, many precast systems with various connection details based on earthquake resistant "monolithic emulation" principle in New Zealand and Italy evolved. One of the critical comments about this kind of development is that there exists a wide range of systems that aredifficult to be standardized, and is also difficult to be socialized.PRESSS Technology research in the USAwas initiated asa response to public preference that the building should experience insignificant damage due tomajor earthquakes so that the repairement is easy to carry out at low cost. This demand had a good response from the precast concrete system.

PRESSS Technology research was led by Priestley in the University of California at San Diego (UCSD). The researchwas carried out for eight years (1994 -2002) and was funded by the National Science Foundation (NSF), Precast / Prestressed Concrete Institute (PCI), and Precast Concrete Manufacturer Association of California (PCMAC). The researchwork was concluded with a full-scale of five-storey buildingsat UCSD. The results were then adoptedand cast into a special section in the American Concrete Code, ACI T1.2-03. The system was then applied to some various building in California,one of them is the 39-floor Paramount Building in San Francisco (2002-2004). An interesting fact, isthat the cost of precast structures are very economical, which was US\$ 8.9 million for for 61,380 meters square or US\$ 145/m²[3].

The PRESSS technology was seriously monitored in New Zealand by Prof. Park, which then appointed Stefano Pampaninin 2005 to perform further development in New Zealand [8].PRESSS technology was then adopted in the New Zealand building code, NZS3101: 2006. The step was then followed by several researches, development, and implementation to various public buildings. In 2010, an important document called PRESSS Design Handbook was published[7].

Major earthquakes in New Zealand that occured in 2010 - 2011due to a series of strong earthquakes caused by the movement of shallow faults[1].An earthquake with a magnitude range of M 5-6, but with a shallow epicentrum(about 10 km), resulted in devastating events that have never been experienced by the people of modern cities of New Zealand. Technically, the modern buildings in New Zealand have been designed by capacity design concept.The earthquake caused severe damages to buildings, but with only a small death toll (only 5 people, compared with an equivalent earthquake in Yogyakarta (2006), which killed about 6000 people).The people made the same complaints (business interuption,high cost repairment, time consuming, and difficult construction) to engineers. In those three seismic events, buildings designed by PRESSS Technology experienced only minor damage.

In Indonesia, precast technology for earthquake-resistant buildingshas been growing rapidly since the launching of the mass housing project in 1995. There are about 59 innovations of precast connection systems, almost all of which are based on the "monolithic emulation" and capacity design concept[11]. So in principle, the Indonesian construction industry is ready to develop and apply the construction technology based on PRESSS

2. PRESSS technology concept

PRESSS technology is considered to be a revolutionary alternative technology that is capable ofproducing highperformance buildings (minimal damage due to major earthquake), and is easy to repair at low cost. The main feature ofthis method is the dry connection among the components using unbonded post-tensioning system. The connection behaves like a spring that tends to restore the building to its original position (self-centering) when experiencing earthquake loads. A framesystemmay be made continuously and beamsmay be connected to the frame with unbonded post-tension system. Wall components are connected vertically. Rocking deformation is controlled to make the building perform well (Fig.1).

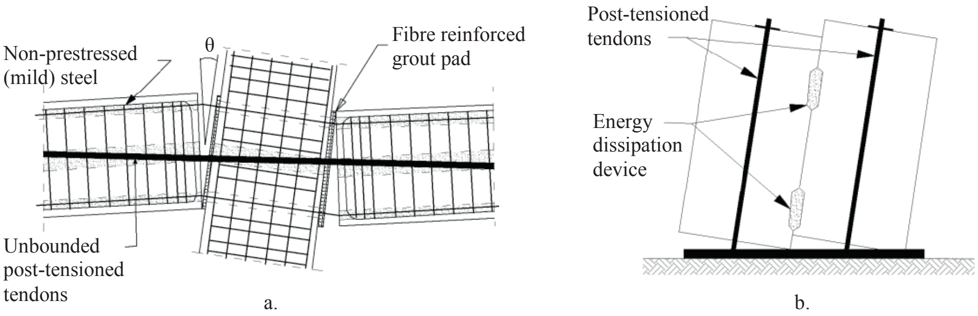


Fig. 1. PRESSS Concept : Full Self-centering with post-tension unbonded connection [7], 1(a) Frame,1(b) Wall

The concepts may be combined with the classical ductile concept using simple tools (made by local industries) as an energy dissipater, that is shown in Fig. 2, this concept is known as the hybrid concept.The dissipater tool can be installed internally (that is shown in Fig. 3) as well as externally (that is shown in Fig. 3). The advantage of external dissipaters is that they could be replaced easily if damaged by major earthquakes.To maintain a keenlook, the tool could be hidden by simple techniques.The ratio of self centering to ductile behavior will result in a hybrid hysteresis spectrum known as flag shape. To obtain economical results, a ratio of combination of 60: 40 is recommended with unbonded post-tension system.

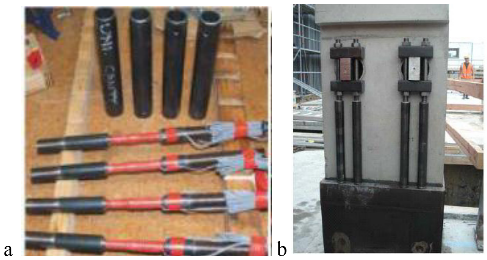


Fig. 2. Dissipater tools, 2(a) in beam, 2(c) in wall [8]

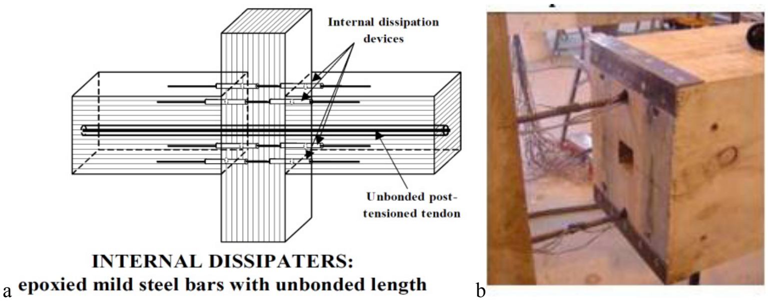


Fig. 3 Internal dissipater, 3(a) schematic, 3(b) examples [8]

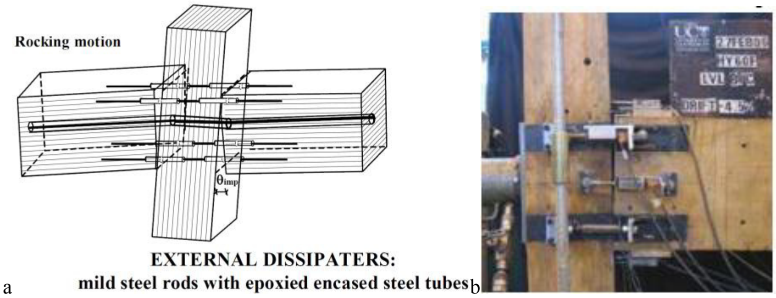


Fig. 4.External dissipater, 4(a) schematic, 4(b) examples[8]

To obtain economical results, a ratio of combination of 60: 40 is recommended with unbonded post-tension system. Ona beam-column interface,a kind of corbel detail developed, which serves as beam support during construction, as well as provides additional shear resistance besides the resistance provided by the prestressing force. Atthe connection between slab and frame, a dry joint detail that can provide an equivalent rigid floordiaphragm effect, is construed.So overall, the skeletal system connected to the dry joint techniques, is faster than the precast system with monolithic emulation wet joint. This systemal so does not require scaffolding.

The use of prestressing systems with better performances compared to the use of reinforced concrete, also givesan opportunity to develop a variety of designs that are more economical. Spans of beams can be increased to obtain optimum design. Another variation is the use of a perimeter frame and/or a perimeter wall with PRESSS

Technology outside, so inside only the gravity resisting frame system is needed. This combination was applied tothe Paramount Building, so as to obtain an economical cost[3].

In the aspect of behavioural modelling, a model known as "monolithic beam analogy" has been developed for the analysis of cross sections and of "lumped plasticitymodel"for the structure analysis model.

3. Research, development and implementation in Indonesia

3.1. The Differential concept between classical capacity design concept and post-tension unbonded system

The difference between the performance of the classical capacity design structure and PRESSS may be observed from the test results of beam-column joint. Fig.5 and Fig. 6,should the hysteresis loops and joint damage pattern meet the requirements of special moment resisting frame (SMRF). The hysteresis loop is fat and the damage occurs in the beam (does not extend into join and columns). The damage is called plastic hinge, which serves as a locus of seismic energy dissipationthat is not easy to repair and causes bussines interuption.

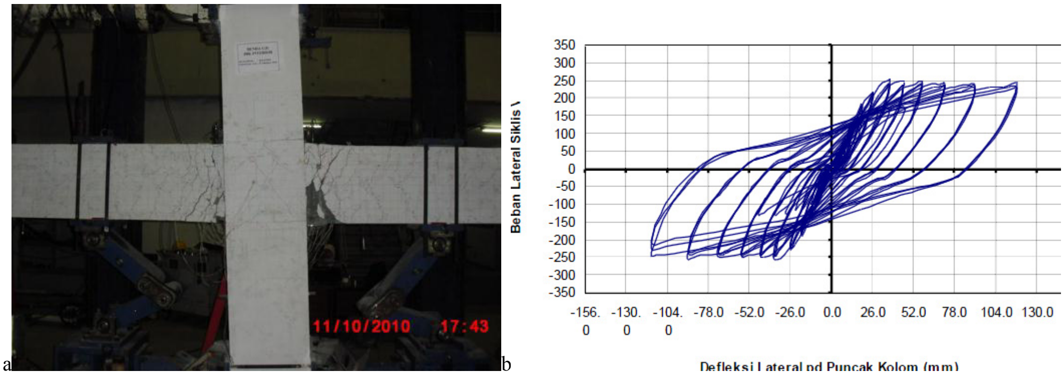


Fig. 5. Pattern of SMRF interior precastjoin complied to ACI 374.1-05[11], 5(a) damage,5(b) hysteresis loop

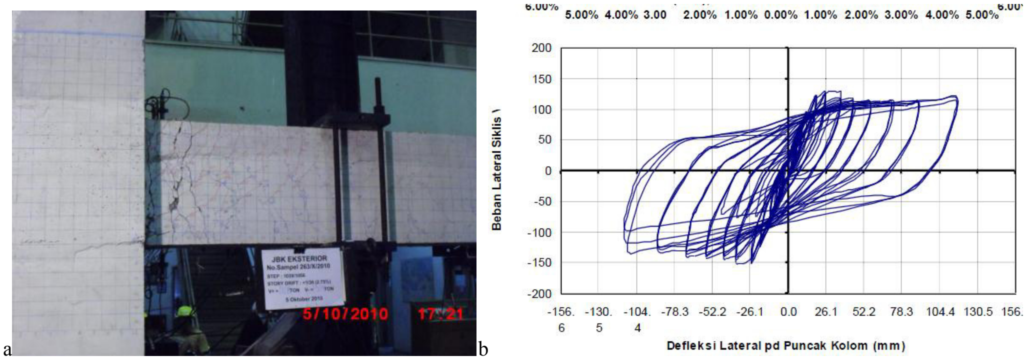


Fig. 6. Pattern of SMRF exterior precast join complied to ACI 374.1-05 [11], 6(a) damage,6(b) hysteresis loop

Fig.7and Fig 8 showshysteresis loop and deformation pattern of a PRESSS beam column joint, with internal and external dissipater, respectively.Unbonded post-tension system provides self-centering effect, so that the structure behaves elastically until a design earthquake load level. If the load exceeds the earthquake design load, this additional load is detained by an energy dissipation device, whichphysical form is analogous to the electrical fuse.

The configuration of a dissipater device consists of the connection of a steel bar using a smaller bar confined within a metal tube sheet. The exceeding load is directed to a smaller bar, having good ductility due to good confinement, that is shown in Fig. 9. This limits the stresses so that no overstrength occurs,which is different to what occurs in classical capacity design. The hysteresis pattern flag shape is a combination of elastic linear post-tension unbonded and Bauschinger effect of steel bars.

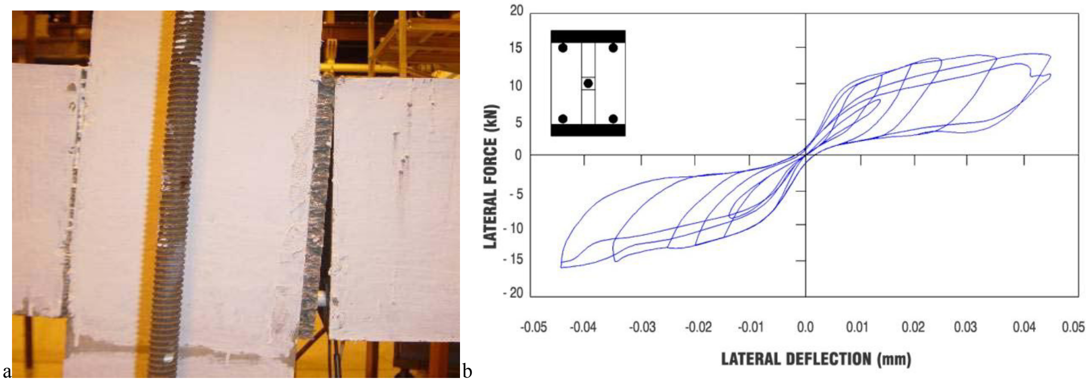


Fig.7. Pattern of PRESSS join test with internal dissipater complied to ACI T1.2-03[7,8], 7(a) damage, 7(b) hysteresis loop

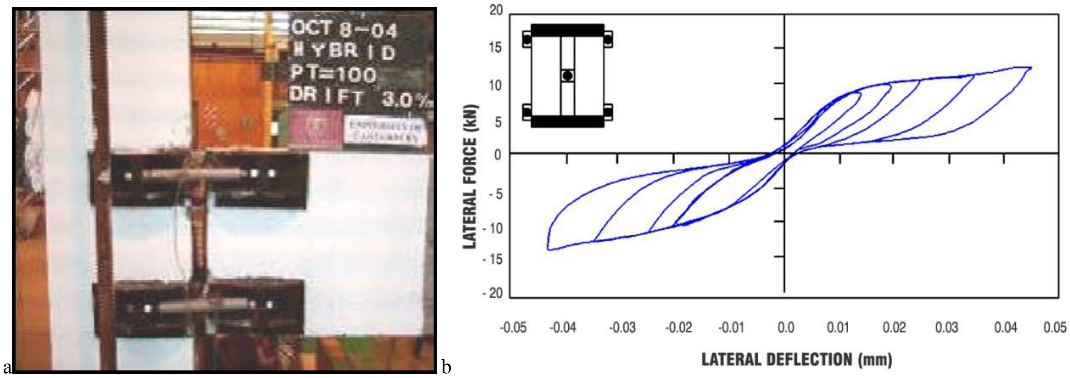


Fig.8. Pattern of PRESSS join test with external dissipater complied to ACI T1.2-03[7,8], 8(a) damage, 8(b) hysteresis loop

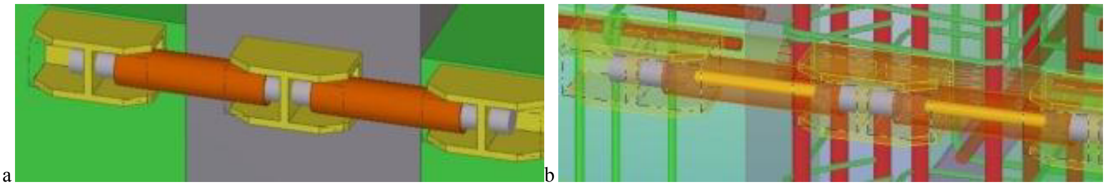


Fig. 9. Schematic of dissipater tool, 9(a) outside, 9(b) inner

3.2. Research and Development in Indonesia

The aims of PRESSS research and development in Indonesia [6] are as follows :

- The confirmation of self-centering behavior of unbonded post-tension system
- The confirmation of ductile behaviorin the hybrid system
- Design and testing of local product dissipaterdevice, confirmation test of beam column joint behaviour
- The testing of the connection of the hollow core system to the frame system

Beam Testing

Gravity load testing was performed on four beam specimens in 2013to meet the purpose of (1) and (2). The first speciment was an ordinary reinforced concrete beam, the second speciment was a pure unbonded post-tension beam, the third speciment was a hybrid concrete beam (50% post tension, 50% reinforcement), and the fourth one was segmental hybrid concrete beam. The load cycle was conformed to ASTM D1143

The documentation and test results are depicted in Fig.10 to Fig. 13 and Table 1 to Table 4. Self-centering system results in insignificant damage, the crack load of the pure post-tension beam was five times that of reinforced concrete beam. Crack load of hybrid beamswas 3.3 times more compared to that of reinforced concrete beam. The ductility of the hybrid system (μ = 23) proved to be even greater than of reinforced concrete beam (μ = 17), so it is thenclassified as Special MomentResisting Frame (SMRF).

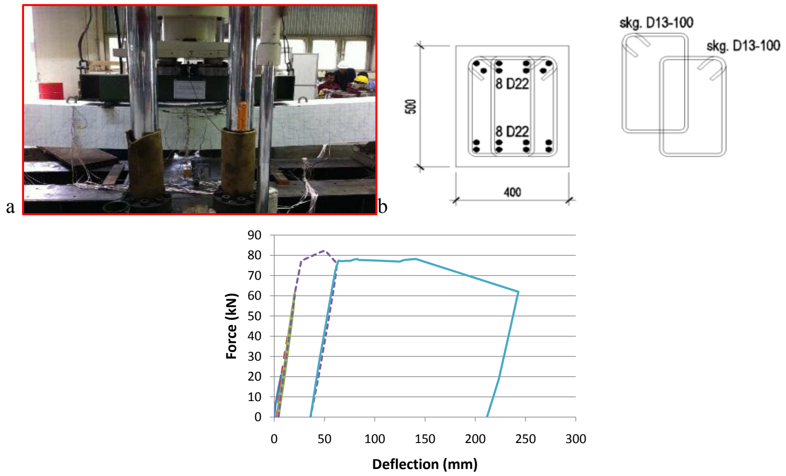


Fig.10. Test result of reinforced concrete beam speciment 10(a) speciment, 10(b) reinforcement,10(c) Load-deflection curve

Table 1. Test analysis of reinforce concrete beam speciment

Moment	Δ (mm)	P(ton)
Crack	1.19	6.22
Yield	14.19	41.5
Maximum	50.59	82.31
Ultimate	242.77	61.94
Ω = 2.01		
f_2 = 1.98		
μ = 17.11		

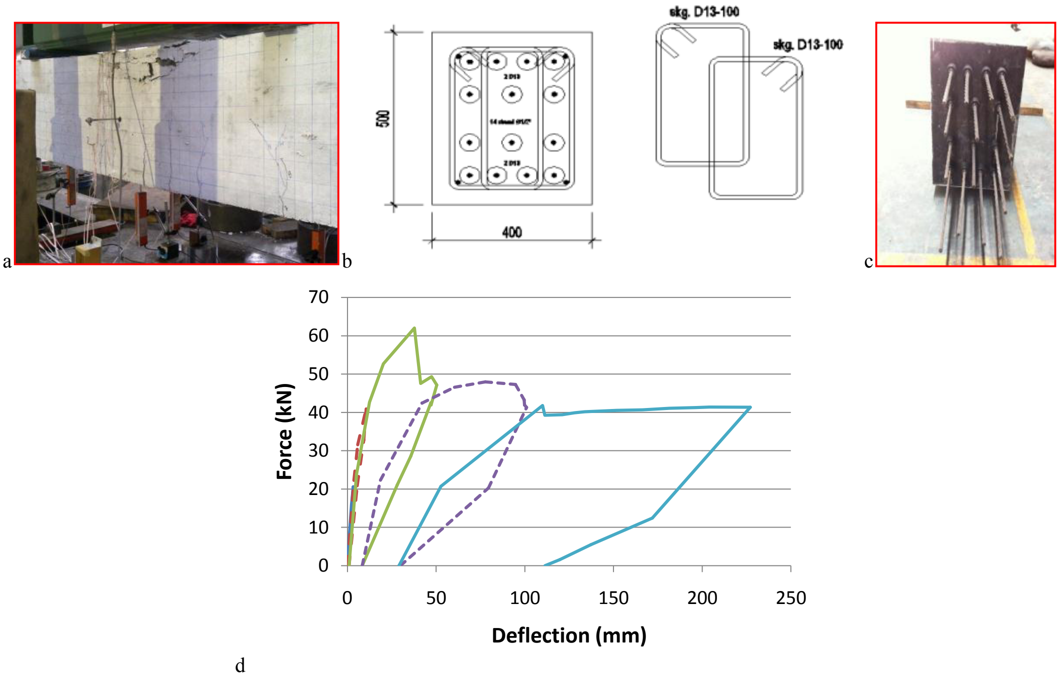
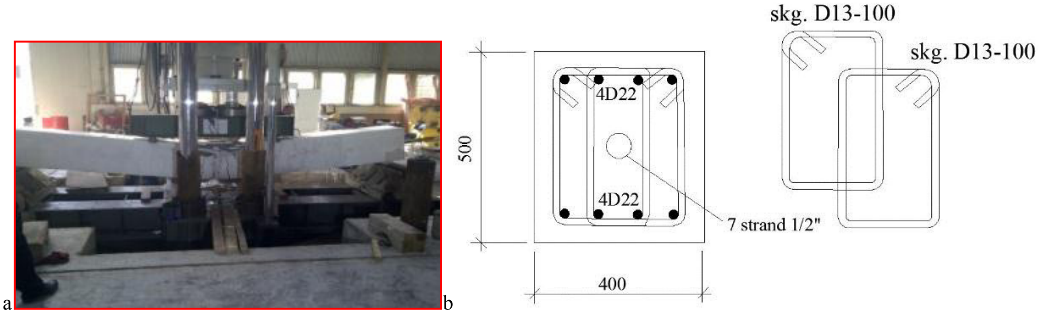


Fig. 11. Test result of post-tension unbonded beam speciment 11(a)speciment, 11(b) & 11(c) posttension,11(d) load-displacement curve

Table 2. Test analysis of post-tension unbonded beam speciment

Moment	Δ (mm)	P(ton)
Crack	5.79	31.57
Yield	20.29	52.67
Maximum	37.39	62.03
Ultimate	227.07	41.35
Ω = 1.51		
f_2 = 1.18		
μ = 11.19		



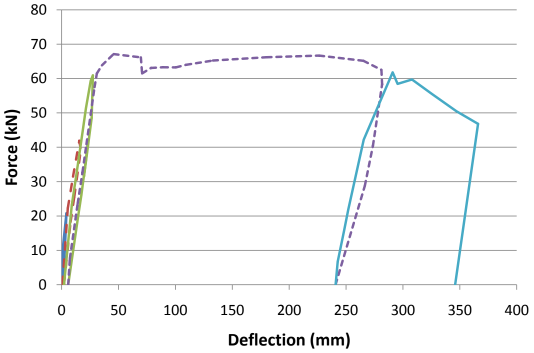


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Fig. 12. Test result of hybrid beam speciments 12(a) speciment, 12(b) reinforcement & tendon,12(c) load displacement curve

Table 3. Test analysis of hybrid beam speciment

Moment	Δ (mm)	P(ton)
Crack	4.19	20,79
Yield	15.59	41.88
Maximum	226.37	66.67
Ultimate	366.06	46.81
Ω = 1.64		
f_2 = 1.59		
μ = 23.48		

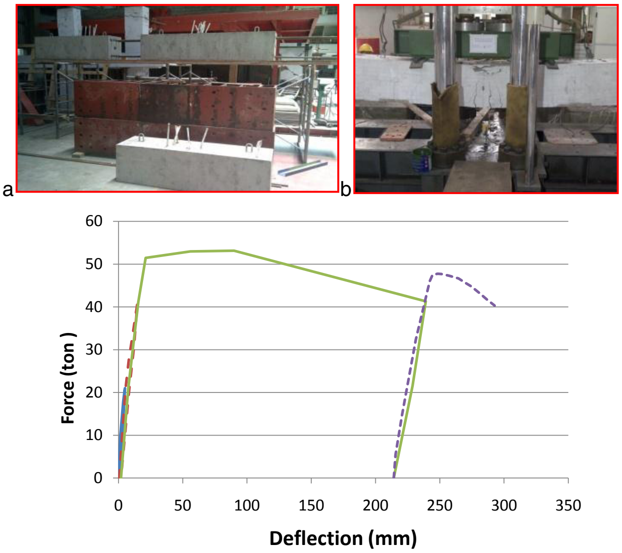

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Fig. 13. Test result of precast hybrid beam speciments 13(a) precast segment, 13(b) speciment, 13(c) load deflection curve

Table 4. Test analysis of segmental hybrid beam speciment

Moment	Δ (mm)	P(ton)
Crack	3.59	17,76

Yield	12.19	30.78
Maximum	89.99	53.15
Ultimate	292.67	40.31
Ω = 1.3		
f_2 = 1.73		
μ = 24.01		

Dissipater Test

A local dissipater device was developed successfully in 2014, based on one of the Indonesian methods of connecting steel bars, with spiral reinforcements made from plain bars, as shown in Fig.14. This spiral is equivalent to metal sheet tubes. The tebsion testing base on ASTM E8 was carried out with the results thatmet requirements, as shown in Fig.15. Dissipater,considered as beam reinforcement, was also tested and provided more information about the behaviour of this beam. Further research will resume in the year 2014.

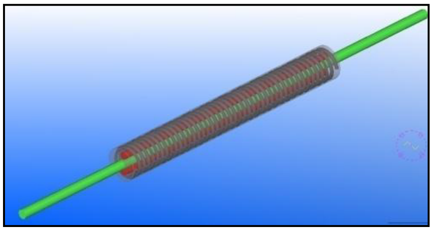
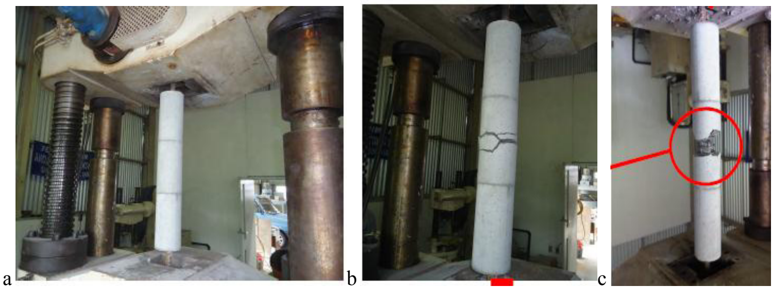


Fig. 14Indonesian method of dissipater



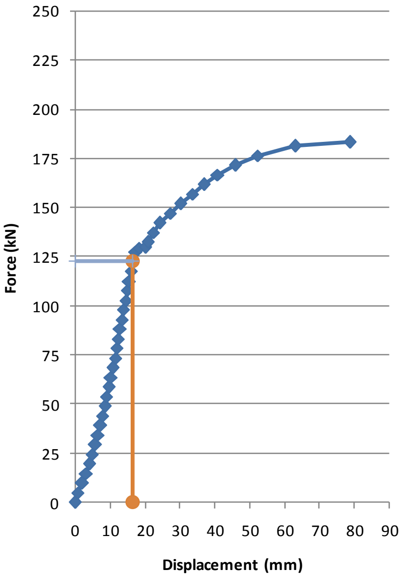


Fig. 15. Test result of local dissipater speciments,15(a) speciment,15(b) crack in dissipater,15(c) failure in smaller bar,15(d) load displacement curve

3.3. Implementattion

Application of PRESSS for buildings in Indonesia, was first performed in March 2014 at a temporary office building in Serpong as shown in Fig.16.

Fig. 16.The documentation of first building using PRESSS,10(a) erection of column,10(b) grouting of colunn,10(c) erection of beam,10(d) grouting of beam,10(e) post tension unbonded installation,10(f) stressing

4. Conclusion

PRESSS is an alternative technology to support the development in earthquake-resistant building design. The Indonesian new earthquake code has been established to comply with the new philosophy, providing significant decrease in structural cost.

This technology is capable to respond to public demands for the design ofhigh performance earthquake-resistant building technologies, which experiences only minor damage due to major earthquakes. The damage is easy to repair with low cost. The support material, method, and equipmentof this technology can be producedlocally.

Presently, an alliance of several precastercompanies is conducting a two year research and development (2013-2014) so that the technology may be applied in Indonesia for years ahead.

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References

[1] B.A.Bradley,A summary of strong ground motions observed in the Canterbury, New Zealand Earthquake Sequence, Proc. 15th World Conference of Earthquake Engineering,Lisboa, Portugal,2012.

[2] C.H.Cuadra, Y. Meguro, Evaluation of the dynamic characteristics of a base-isolated low-rise RC building after the great east Japan earthquake, Proc. 15th World Conference of Earthquake Engineering, Lisboa, Portugal, 2012.

[3] R.E. Englekirk, Design-construction of the Paramount a 39 story precast prestressed concrete apartment building, J. PCI. July–August (2002).

[4] M. Irsyam,I.W. Sengara., Laporan peta zonasi gempa, Kementerian Pekerjaan Umum, 2010.

[5]A.M.B.S. Islam, M. Jameel, M.Z. Jumaat, Seismic isolation in buildings to be a practical reality : behavior of structure and installation technique, J. Eng. Tech. Research.3(4) (2011).

[6]H.N.Nurjaman, B.Hariandja, R. Rivky, Research, development and application of precast system for building, with connections using pretressed unbonded post-tension, Proc of. Cecar The 6th Civil Engineering Conference in Asia Region., Jakarta, Indonesia, 2013.

[7] S.Pampanin, PRESSS design handboook, New Zealand Concrete Society, 2010.

[8]S. Pampanin, Reality-check and renewed challenges in earthquake engineering : implementeing low-damaged structural system – from theory to practice, Proc. 15th World Conference of Earthquake Engineering, Lisboa, Portugal, 2012.

[9] T. Paulay, Simplicity and confidence in seismic design,The Fourth Mallet-Milne Lecture, SECED John Wiley & Sons, Chicester, United Kingdom, 1993.

[10]Puslitbangkim, Laporan hasil uji balok dan dissipater, Bandung, Indonesia, 2014.

[11]S.Yuwasdiki, Prosedur pendaftaran dan penerimaan sertifikasi sistem pracetak beton di Puslitbang Permukiman Kementerian Pekerjaan Umum, Proc of. Sosialisasi SNI Gempa dan Konstruksi Pracetak dan Prategang untuk Bangunan Gedung. Puslitbangkim-IAPPI, Jakarta, Indonesia, 2013