ABSTRAK

Banyak ditemukan struktur bangunan beton bertulang yang perlu perkuatan (*strengthening*) akibat kesalahan dalam perencanaan (*detail engineering design*), pemberian beban yang berlebih (*overload*), dan pelaksanaan konstruksi yang salah. Realita yang ada sebagian besar struktur lama (*eksisting*) masih menggunakan filosofi perencanaan berdasarkan peraturan beban gempa lama. Sehingga sebelum terjadi gempa kuat maka balok perlu perkuatan berupa balok *haunch.* Balok *haunch* meningkatkan kapasitas momen dan geser serta merelokasi posisi sendi plastis (*plastic hinge*) menjauh dari muka kolom. Metode perkuatan dengan penambahan balok *haunch* di muka kolom, meningkatkan kekakuan, kekuatan dan ketahanan struktur sehingga gejala *debonding* di hubungan balok kolom (HBK) dapat dihindari. Daktilitas balok *haunch* lebih baik dibanding daktilitas balok prismatis, hal ini dikarenakan rasio tulangan (ρ) balok *haunch* relatif lebih kecil dibanding balok prismatis.

Beton geopolimer merupakan salah satu beton alternatif yang tidak menggunakan semen (*non cement based)* sebagai bahan pengikat dan sebagai gantinya digunakan abu terbang (*fly ash*) yang kaya akan silika dan alumina yang dapat bereaksi dengan cairan *alkaline activator* (Na_2SiO_3 dan NaOH) untuk menghasilkan bahan pengikat (*binder*). Penggunaan *fly ash* di sisi lain memiliki dampak positif karena bahan ini merupakan limbah pembakaran batu bara. Beton geopolimer memiliki kekuatan ikatan atau daya lekat (*bond*), kuat tekan dan kuat tarik yang lebih tinggi dibanding beton konvensional. Untuk pelaksanaan perkuatan balok di muka kolom perlu menggunakan beton geopolimer yang dapat memadat sendiri (*self compacting geopolymer concrete* - SCGC), hal ini mengingat perkuatan balok di muka kolom mempunyai tingkat kesulitan pelaksanaan dan keterbatasan ruang yang sempit akibat keberadaan pelat dan balok eksisting. Penggabungan konsep perkuatan balok di muka kolom menggunakan balok *haunch* dengan pemanfaatan SCGC mempunyai manfaat ganda. Penelitian disertasi ini mengedepankan inovasi berupa solusi teknis penanganan perkuatan balok di muka kolom berupa balok *haunch* yang terbuat dari beton geopolimer yang dapat memadat sendiri (*self compacting geopolymer concrete* – SCGC). Pendekatan analisa dilakukan melalui uji eksperimental skala penuh (*full scale*) di laboratorium dan permodelan elemen hingga, untuk menjelaskan aspek-aspek mikro sebagai pelengkap pengujian. Data yang digunakan untuk analisis berupa data primer yang diperoleh dari hasil pengukuran dan perekaman dalam eksperimen yang dilakukan, serta pengamatan model elemen hingga. Penelitian ini diawali dari uji material bahan penyusun benda uji berupa uji tarik besi tulangan. Untuk beton konvensional maupun beton geopolimer akan dilakukan uji kuat tekan, uji kuat tarik belah dan uji kuat tarik lentur beton. Data tersebut digunakan untuk *input* model numeris. Pembuatan benda uji balok beton prismatis dan balok *haunch* dengan mutu f'_c=31 MPa. Dimensi balok uji dengan panjang balok 3800 mm, penampang balok dengan lebar 170 mm dan tinggi 340 mm serta konfigurasi penulangan dengan kaidah *under reinforced.* Balok *haunch* mempunyai variabel tetap yaitu dimensi panjang balok *haunch* : $L=2\times H$ dan variabel bergeraknya adalah tinggi balok *haunch* (*h*).

Hasil pengujian balok lentur akibat beban monotonik terhadap benda uji balok prismatis maupun balok *haunch* ditampilkan dalam kurva hubungan beban - lendutan, momen-kurvatur dan pengamatan pola retak. Berdasarkan hasil uji eksperimental dan analisis terhadap delapan (8) benda uji yang terdiri dari dua (2) balok prismatis (BC), dua (2) balok *haunch* geopolimer (BG0.5), dua (2) balok *haunch* geopolimer (BG1.0) dan dua (2) balok *haunch* konvensional (BK1.0) dapat disimpulkan : **(a).** Diperoleh komposisi SCGC balok *haunch* : agregat kasar 42.0% ; agregat halus 28.0% ; *fly ash* (FA) 19.5% ; *alkaline activator* (AA) 10.5% ; *superplasticizer* 2.0% dari FA ; *extra* *water* 11.70% dari *binder* (FA+AA) ; *extra cement* 5.63% dari *binder* (FA+AA). AA terdiri dari NaOH 12 M dan Na_2SiO_3 Be 52 dengan perbandingan NaOH : Na_2SiO_3 = 1.0 : 2.5. **(b).** Perbedaan kapasitas beban, daktilitas *displacement* maupun daktilitas kurvatur antara balok *haunch* geopolimer BG1.0 dan balok *haunch* konvensional BK1.0 cukup signifikan. Hal ini dikarenakan beton geopolimer mempunyai nilai susut yang cukup besar (667 $\mu\varepsilon$) sehingga menyebabkan *initial crack* material terjadi pada beton geopolimer (BG). **(c).** Dibandingkan dengan balok prismatis, besarnya peningkatan kapasitas beban balok BK1.0. sebesar 73.27% dan BG1.0. sebesar 71.97% serta BG0.5. sebesar 54.70%. **(d).** Terhadap balok prismatis (BC), besarnya peningkatan daktilitas *displacement* (μ_d) balok BK1.0. sebesar 43.40% dan balok BG1.0. sebesar 25.10% serta balok BG0.5. sebesar 3.91%. Hal ini karena pada BG0.5 dengan tinggi balok *haunch* yang belum optimal sehingga peningkatan relatif kecil. **(e).** Jika dibandingkan dengan balok prismatis (BC), besarnya peningkatan daktilitas kurvatur (μ_φ) balok BK1.0. sebesar 46.89% dan balok BG1.0. sebesar 32.03% serta untuk balok BG0.5. mengalami peningkatan sebesar 7.23%. **(f).** Sendi plastis pada balok prismatis BC dan balok *haunch* BG0.5 terjadi tepat di muka kolom, sedang balok BK1.0. maupun BG1.0. terjadinya sendi plastis di ujung balok *haunch* (2×H dari muka kolom). **(g).** Sendi plastis (*plastic hinge*) dapat bergeser pada ujung *haunch* dengan syarat minimal sudut *haunch* (α) sebesar 19.07^o atau tinggi *haunch* (h) minimal sebesar 0.7×tinggi balok prismatis (0.7×H). **(h).** Pola retak (*crack pattern*) balok *haunch* dan balok prismatis akibat beban monotonik menunjukkan pola retak balok prismatis dimulai dari propagasi retak di muka kolom dan balok *haunch* di ujung *haunch*. **(i).** Model sebagai alat bantu dan pembanding yang memberikan prediksi perilaku beban, lendutan, dan pola propagasi *crack* yang relatif sama terhadap hasil uji eksperimental. Hal ini menunjukkan bahwa model dapat digunakan untuk memprediksi perilaku keruntuhan balok beton bertulang. Model juga dapat menyimulasikan tinggi *haunch* 0.7×H dengan kesimpulan bahwa terbukti tepat tinggi *haunch* 0.7×H maka telah terjadi pergeseran sendi plastis dari muka kolom ke ujung balok *haunch*.

Kata kunci: *strengthening*, balok *haunch*, SCGC, daktilitas *displacement* dan kurvatur, *plastic hinge*.

ABSTRACT

Many reinforced concrete structures are found that need strengthening due to mistakes in detail engineering design, overloading, and incorrect quality of construction. Reality is most of existing structures still use a planning philosophy based on the old earthquake load codes. So that before a strong earthquake occurs, the beam needs strengthening with haunch beam. The haunch beam increases the moment and shear capacity and relocates plastic hinge away from the column face. Strengthening method with haunch beams at the front of the column face increases stiffness, strength and durability of the structure so that debonding symptoms in the beam column joint can be avoided. Ductility of the haunch beam is better than ductility of the prismatic beam, this is because the reinforcement ratio (ρ) of the haunch beam is relatively smaller than prismatic beam.

Geopolymer concrete is an alternative concrete that does not use cement as a binder and instead uses fly ash which is rich in silica and alumina which can react with alkaline activator liquid (Na_2SiO_3 and NaOH) to produce binders. On the other hand, use of fly ash has a positive impact because this material is a waste of coal combustion. Geopolymer concrete has a higher bond, compressive and tensile strength than conventional concrete. For strengthening of beam in front of the column it is necessary to use self-compacting geopolymer concrete (SCGC), because strengthening of beam in front of the column has a difficulty level of implementation and limited space due to there are of existing slabs and beams. Combining the concept of strengthening beam in front of column using haunch beams with the use of SCGC has two benefits. This dissertation research puts forward innovation in the form of technical solutions for handling strengthening beam in front of the column with haunch beams made of self-compacting geopolymer concrete (SCGC). Analytical approach is carried out through full-scale experimental tests in the laboratory and finite element modeling, to explain micro aspects as a complementary test. The data used for analysis in the form of primary data obtained from the results of measurements and recordings in the experiments carried out, as well as observations of the finite element model. This research begins with the test of the materials that make up the test object in the form of a tensile test for steel. For conventional concrete and geopolymer concrete will be tested for compressive strength, split tensile strength test and flexural tensile strength test of concrete. The data is used to input the numerical model. Manufacture of prismatic concrete beams and haunch beams with a quality of f'_c=31 MPa. Dimensions of the test beam with a beam length of 3800 mm, beam cross section with a width of 170 mm and a height of 340 mm and the reinforcement configuration with under reinforced rules. The haunch beam has a fixed variable, namely the length dimension of the haunch beam: $L=2\times H$ and the unfixed variable is the height of the haunch beam (h).

The results of bending beam test due to monotonic load on the prismatic and haunch beam are expressed in the load–displacement, moment-curvature and observation of crack patterns. Based on experimental test results and analysis of eight (8) specimens consist of two (2) prismatic beams (BC), two (2) geopolymer haunch beams (BG0.5), two (2) geopolymer haunch beams (BG1.0) and two (2) conventional haunch beams (BK1.0) can be concluded: **(a).** Obtained SCGC composition of haunch beams: 42.0% coarse aggregate; fine aggregate 28.0% ; fly ash (FA) 19.5% ; alkaline activator (AA) 10.5% ; superplasticizer 2.0% of FA ; extra water 11.70% from binder (FA+AA); extra cement 5.63% of binder (FA+AA). AA consists of NaOH 12 M and Na_2SiO_3 Be 52 with a ratio of NaOH: Na_2SiO_3 = 1.0: 2.5. **(b).** The difference in load capacity, displacement ductility and curvature ductility between BG1.0 geopolymer haunch beam and the BK1.0 conventional haunch beam is quite significant. This is because geopolymer concrete has a fairly large shrinkage value (667 $\mu\varepsilon$) so that it causes initial crack material to occur in geopolymer concrete (BG). **(c).** Compared to prismatic beams, the magnitude of the increase in load capacity of BK1.0 beams by 73.27% and BG1.0. of 71.97% and BG0.5 by 54.70%. **(d).** Compare to prismatic beams (BC), the magnitude of the increase in displacement ductility (μ_d) beam BK1.0. is 43.40% and beam BG1.0. is 25.10% and beam BG0.5. is 3.91%. This is because at BG0.5 with a haunch beam height that is not optimal so that the increase is relatively small. **(e).** When compared to prismatic beams (BC), the magnitude of the increase in curvature ductility (μ_φ) beam BK1.0. is 46.89% and beam BG1.0, by 32.03% and for beams BG0.5, an increase of 7.23%. **(f).** Plastic hinges in prismatic beams BC and haunch beams BG0.5 occur in face of column, while beams BK1.0 and BG1.0. the occurred plastic hinge at the end of the haunch beam (2×*H* from face of column). **(g).** Plastic hinge occurs at the end of haunch with minimum haunch angle (α) is 19.07^o or haunch height (*h*) is at least 0.7×height of prismatic beam (0.7×*H*). **(h).** Crack pattern of haunch beam and prismatic beam due to monotonic load shows a prismatic beam crack pattern starting from the crack propagation at face of column and haunch beam at the end of haunch. **(i).** The model as a tool and comparison that provides predictions of load behavior, deflection, and crack propagation patterns are relatively the same as the experimental test results. This shows that the model can be used to predict the failure behavior of reinforced concrete beams. The model can also simulate haunch height of 0.7×*H* with conclusion that it is proven that haunch height is 0.7×*H*, so there has been move the plastic hinge from face of column to the end of haunch beam.

Keywords: strengthening, haunch beam, SCGC, displacement and curvature ductility, plastic hinge.