Seismic Behavior and Evaluation of Concrete Members Made of A Large Quantity of Fly Ash

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(Degree)
博士（学術）

(Date of Degree)
2016-09-25

(Date of Publication)
2017-09-01

(Resource Type)
doctoral thesis

(Report Number)
甲第6734号

(URL)
https://hdl.handle.net/20.500.14094/D1006734

(別紙様式 3)

論文内容の要旨

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専　攻　建築学

Seismic Behavior and Evaluation of Concrete Members Made of A Large Quantity of Fly Ash

フライアッシュを大量配合したRC部材の耐震性能と評価方法

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1. Background

Modern industry development has brought massive wealth, meanwhile it has also caused serious environment problems such as greenhouse effect and air pollution, and more serious industry resource shortage. Therefore, building sustainable society which can save energy, consume less carbon and protect environment has gradually become the consensus in the world in the 21st century. As the field consuming lots of resource and energy, researchers and designer in civil engineering are also devoting their efforts to make some contributions to the development of sustainable society.

It is well known that, the thermal power generation produces huge amount of dust, more than 90 percent of which is fly ash, causing a series of environment problems. Therefore, there will be significant society meaning for the sustainable development in the use of the fly ash in the civil engineering construction as the substitute of other resources such as cement and sand, since this utilization of fly ash can reduce the environment problems stated above and save the resources and energy.

In the last several decades extensive researches on fly ash concrete as a kind of energy saving material have been comprehensively conducted in the world. Since 1950s, fly ash has found its wide applications in cement and concrete industries. In North America, fly ash has been used mainly as a supplementary cementitious material in the production of Portland cement concrete at replacement levels ranging from 15% to 30% by mass of the total cementitious material. Since 2000, high volume fly ash concrete with fly ash replacement level larger than 30% has gained increasing attention from the standpoint of reducing environmental burden caused by the production of cement. In Japan, the last two decades has seen the recycling ratio of fly ash increase from 67% to about 97% with about 65% of fly ash being used as raw material for Portland cement. On the other hand, while the annual domestic consumption of Portland cement declined from its peak of 86.5 million tons in 1990 to 43.7 million tons as of 2013.

However, the thermal power generation is boosted due to the security consideration after 3.11 Eastern Japan Earthquake in 2011, and the amount of fly ash produced by thermal power generation is gradually increasing, while the cement production, the main filed to consume fly ash now, is decreasing because of the depressed construction market. This fact implies that further use of fly ash as raw material for cement can no

longer be expected in Japan. A new application of fly ash is desirable.

From the viewpoint of maximizing environmental and economic benefits simultaneously, Matsufuji et al have proposed to utilize fly ash to partially replace fine aggregate and make high-performance structural concrete. Through extensive experimental works, Matsufuji et al demonstrated that compressive strength of the concrete with fly ash partially replacing not Portland cement but sand kept increasing along with the fly ash content till the replacement level reached 640 kg/m^3 if the concrete mixture met the minimum requirements prescribed in JASS5 for structural concrete. Matsufuji et al have also developed an empirical formula to predict compressive strength of the concrete with fly ash partially replacing fine aggregate, and verified that the optimum upper replacement level of fly ash would be about 455 kg/m^3 without compromising workability and casting of the produced concrete. The advantage of the method proposed by Matsufuji et al. to largely use fine fly ash lies in that it could provide high concrete strength and sounder durability simultaneously, and reduce the amount of sand from river, mountain and sea, which significantly contribute to mitigate environmental burden by concrete industry.

As compared with steel structures and wood structures, concrete structures are still most widely used in the world due to good structural performances, excellent durability, fire resistance efficiency, and high cost performance. However, concrete structures have inherent shortage such as brittle characteristics. The method increasing the amount of stirrups in the concrete structure has been proposed in current concrete structural design codes in many countries to improve the ductility of concrete, and the largest spacing of stirrup has been limited to 100mm.

It has been found that the performances of many buildings designed according to current design codes can attain the goal of life safety, but some buildings can't reach that goal although they were designed by ductility design method as summarized in the survey reports of observed damage of buildings in recent mage-earthquakes such as the 2008 Sichuan Earthquake and the 2011 Eastern Japan Earthquake. In addition, several buildings which didn't collapsed during the earthquakes had to be demolished because the residual deformation of them was so large that they couldn't been used anymore or the repair costs would be very expensive. These phenomenon indicates that ductile concrete structures could no longer be regarded as the only solution for the buildings

constructed in earthquake-prone regions. From the lessons from the 1995 Kobe earthquake, Ohtani and Kawasima pointed out the importance of limiting the residual deformation in 1997, respectively.

Based on the backgrounds described above, a new type of building structure needs to be developed to mitigate the environmental burden and enhance the robustness and reparability of buildings structures. In other words, sustainability and resilience shall be two key words for the next generation of building structures located in seismic regions.

2. Objectives and scope

On the basis of the above-mentioned backgrounds and reviews of previous studies, it is reasonable to presume that the utilization of LQFA in concrete and the use of ultra-high strength SBPDN rebar as longitudinal steel in concrete columns are a feasible way to the development of sustainable and resilient concrete components.

Objectives of this doctor dissertation are to develop a new type of sustainable and resilient concrete columns and experimentally investigate their seismic performance, to propose design equations for predicting ultimate shear strength and deformation of concrete components made of LQFA, to develop a skeleton model for the proposed concrete columns, and finally to propose a cyclic loop model of the proposed columns.

The concrete contents of this doctor desertion are summarized as follows:

1) Experimental investigation of seismic behavior of circular concrete cantilever columns made of LQFA and reinforced with SBPDN rebars to clarify if the LQFA concrete beams can exhibit the same resilience as the conventional circular concrete columns and if the resilience may change due to the increased compressive strength of LQFA concrete. These columns simulates the columns at the lower stories of high-rise frame structures, which are expected to exhibit a strong column-weak beam lateral resistance mechanism.

2) Experimental investigation of seismic behavior of circular concrete columns made of LQFA and reinforced with SBPDN rebars under double-curvature deformation. These columns simulate the columns in a frame expected to exhibit the weak column-strong

beam failure mechanism, which was well observed in low- and middle-rise building structures damaged during recent strong earthquakes.

3) Proposal of design equations to calculate the ultimate shear strength and corresponding drift or chord rotation of LQFA concrete beams. These proposed equations are intended not only for LQFA concrete beams but also for LQFA concrete columns. With the proposed equations, one can conduct reasonable and reliable design of the developed sustainable and resilient concrete columns.

4) Modeling of skeleton curve of lateral force versus drift ratio relationship for circular LQFA concrete columns. In this paper, the model will be referred to as capacity curve, which is indispensable in performance-based design of the proposed sustainable and resilient concrete columns.

3. Format of the doctor dissertation

This doctor dissertation comprises six chapters. Each chapter deals with one of the above-mentioned issues except chapter one and chapter six. Core points of each chapter are written below:

Chapter one introduces backgrounds of this doctor dissertation, reviews previous study in the literature, and presents research objectives and research issues.

Chapter two is devoted to the investigation of seismic behavior of circular concrete cantilever columns. Four specimens were fabricated and tested under combined reversed cyclic loading and constant axial compression. Experimental variables were the type of longitudinal rebar and the confinement method. All specimens were 250mm in diameter and had shear span ratio of 2.0. Two specimens were reinforced by eight SBPSN (12.6mm in nominal diameter) rebars, and two specimens by eight high-strength deformed USD685 rebars. Longitudinal rebars were uniformly distributed along the perimeter of column section with concrete shell of 30mm and gave steel ratios of 2.05% and 2.07%, respectively. Objectives of this experimental work are to investigate effect of the high compressive strength of LQFA concrete on the resilience of columns, and to verify effectiveness of partial confinement of columns by steel plates

on seismic capacity of high-strength concrete columns.

Chapter three presents experimental study on seismic performance of circular LQFA concrete columns under double curvature deformation. Four circular columns with diameter of 250mm were made and tested under reversed cyclic loading while the axial load was kept constant. All specimens were made of concrete with fly ash replacement of 455 kg/m3 of sand and partially confined by circular steel plates within end region of 375mm from the column base. Experimental variables were the connecting method of steel plates for confinement, the type of longitudinal rebars (USD685 and SBPDN) and the anchorage length of SBPDN rebars within the loading stubs. The shear span ratio and axial load level expressed in terms of axial load ratio were kept constant for all specimens and had values of 2.0 and 0.33, respectively.

Chapter four describes an experimental program to investigate shear behavior of LQFA concrete beams. Emphasis of the program was placed on the assessment of ultimate shear strength and deformability of LQFA concrete members, whose shear capacities have been little known because the use of fly ash in large quantities leads to high strength concrete that tends to fail after the yielding of longitudinal rebars. To obtain experimental information on the ultimate shear capacities of LQFA concrete members, the SBPDN rebars were used as tensile steels for all twenty specimens, all of which were prismatic beams with rectangular section of 250 x 150 mm. Experimental variables among specimens were the shear span ratio of beams (1.0 – 4.0) and the steel ratio of tensile rebar (0.76%, 1.14%). Based on the test results, the equilibrium of forces acting on the diagonal shear plane and Mohr-Coulomb failure criterion for LQFA concrete, a complete shear strength model is developed and its validity and accuracy is verified by comparing the experimental results with the calculated results.

A skeleton envelop curve is developed in Chapter five for circular LQFA concrete columns. The capacity curve model is developed on the basis of the test results described in Chapters two and three of this dissertation. The proposed model takes effect of slippage of SBPDN rebars on capacity curve into consideration. Test results described in this study are used to verify validity and accuracy of the developed model.

Chapter six summarizes all findings and observations obtained through Chapters two and five, and presents several future issues concerning with the proposed sustainable

and resilient concrete components.

4. Conclusion

1. In chapter 2, four circular concrete cantilever columns were tested to investigate effects of combination of a large quantity of fine fly-ash, ultra-high-strength rebar with low bond strength, and confinement by thin steel plates, on seismic behavior of concrete columns under single-curvature deformation. From the experimental results described in this chapter, the following conclusion can be drawn.

(1) Combination of a large quantity of fine fly-ash, ultra-high-strength rebar with low bond strength, and confinement by thin steel plates is a simple but effective method to create robust and resilient concrete components. The circular LQFA concrete cantilever columns with SBPDN rebars and under axial compression with axial load ratio of 0.33 showed higher resilience than the columns with USD 685 rebars.

(2) While high compressive strength of concrete due to high fly ash replacement level of 455 kg/m^3 reduced deformability or stability of LQFA concrete columns, utilization of SBPDN rebars as longitudinal rebars and proper confinement by spirals could ensure stable increment of lateral resistance up to the drift level of 0.04 rad. Confinement by steel plates in lieu of spirals could further enhance that drift level up to 0.05rad.

(3) Utilization of USD 685 rebars could ensure LQFA concrete columns stable response and higher early lateral resistance until R=0.025 rad. The high bond-strength of USD rebar, however, tended to cause yielding of it earlier than SBPDN rebar, resulting in degradation of lateral resistance of the columns after R=0.025 rad. Even the confinement by steel plates could not enhance this critical drift level.

(4) Residual drift angle, a well-known and adopted indicator for the reparability of concrete components, was primarily dependent upon if the longitudinal rebars yielded. Confinement method exhibited little, in any, influence on the residual drift angle. Once longitudinal rebars commenced yielding, tensile or compressive, the residual drift would increase at a much higher rate than that before the yielding, which implies that delay of the yielding of longitudinal rebar is crucial to the resilience of concrete members.

2. In chapter 3, four circular columns were fabricated and tested to investigate robustness and resilience of circular LQFA concrete beam-columns reinforced with SBPDN rebars and confined by thin steel plates. From the experimental results described in this chapter, the following concluding remarks can be made.

(1). Combination of a large quantity of fly-ash, ultra-high strength rebar with low bond strength and confinement by thin steel plates is a simple and effective method to make sustainable and resilient concrete beam-columns.

(2). While compressive strength of LQFA concrete was beyond 70MPa, combination of SBPDN longitudinal rebar and partial confinement by thin steel plates could ensure circular LQFA concrete beam-columns sufficient resilience until drift angle reached 0.05rad even when the columns were under relatively high axial compression with axial load ratio of 0.33.

(3). Uniting steel plates by bolts and nuts to form a steel tube could provide high strength concrete the same confinement effect as the welded steel tube. When using thin steel plates to confine high-strength concrete, the bolted tube can work more reliably that the welded tube, which has a risk of rupture near the welding portion at large deformation.

(4). To ensure LQFA concrete beam-columns a resilience up to 0.05 rad, the tie plate should be embedded at the contra-flexure section of column to anchor SBPDN rebars and reduce their slippage.

(5). Shorting the anchorage length of longitudinal bar within beam-column joint had little, in any, influence on the overall seismic performance of LQFA columns.

3. In chapter 4, twenty concrete beams were tested under combined shear and bending in order to obtain basic information on the shear behavior of LQFA concrete beams with emphasis placed on the evaluation of ultimate shear strength and deformability. The fly ash was used to primarily replace fine aggregate and the replacement level of fly ash was 455 kg/m^3 for all specimens. Based on the test results, a complete shear capacity model were developed to trace the variation of shear resistance of LQFA concrete members along with deformation (chord rotation or drift ratio). From the experimental

and analytical works described in this chapter, the following conclusions can be drawn:

1) While the compressive strength of LQFA concrete was beyond 70 MPa, shear failure of LQFA concrete beam occurred along a primary diagonal plane by about 45-degree with respect to the beam axis as observed in general normal-strength concrete beams despite the difference in the shear span and the steel ratio of hoop.

2) The shear resistance by the concrete in LQFA concrete beams was strongly affected by the shear span (a/d) ratio, a factor indirectly accounting for the so-called size effect of structural member on the concrete strength. For the short LQFA concrete beams with the *a/d* ratio of 1.0, the ultimate shear strength and chord rotation depended more upon the shear span ratio than the steel ratio of hoop. Increasing the steel ratio of hoop from 0.19% to 0.76% only brought about 10% increment in ultimate shear strength and chord rotation. On the other hand, for the LQFA concrete beams with the *a/d* ratio larger than 1.5, the ultimate shear strength and chord rotation increased significantly along with the steel amount of hoop.

3) Based on the equilibrium of the forces acting on the diagonal shear plane and Mohr-Coulomb criteria for LQFA concrete, equations (Eq. (4-7) and Eq. (4-8)) were developed to predict the ultimate shear strength of rectangular and circular LQFA concrete members, including beams and columns. These equations can reasonably and accurately account for effect of the shear span ratio on the shear resistance by LQFA concrete, and give more accurate prediction of the measured shear strength than the equations prescribed in current design codes. The ratio of the experimental/calculated shear strength has a mean value of 1.02, and a standard deviation of 0.14.

4) The ultimate chord rotation or drift ratio of LQFA concrete members exhibited very strong correlation with the factor β, which is the ratio of the calculated shear strength to the calculated flexural strength. A linear equation (Eq. (4-9)) was proposed to predict the ultimate deformation. The proposed equation gives a relatively accurate prediction of the measured results. The ratio of the experimental/calculated deformation has a mean value of 0.99, and a standard deviation of 0.21.

5) On the basis of test results of LQFA concrete beams which failed in shear, a complete shear capacity curve for LQFA concrete members was developed. The

proposed model defines the shear resistance of LQFA concrete members as a multi-linear function of drift ratio or chord rotation, and hence can trace the change or degradation of shear strength along with deformation. The predicted shear capacity curves exhibited fairly good agreement with the measured results of both rectangular LQFA concrete beams and circular LQFA concrete columns, which implies reliability and accuracy of the proposed model.

6) Due to their simplicity and accuracy, the proposed equations enable structural engineers to conduct reasonable and reliable shear design of LQFA concrete members, promoting the application of LQFA concrete to building structures and contributing to reducing environmental burden by concrete industry.

4. In chapter 5, in order to develop a simple model to depict the capacity curve of circular LQFA concrete columns reinforced by SBPDN rebars that are expected to behave in a stable manner till large drift under seismic loading, an analytical method is proposed. This method can distinguish contribution of potential displacements to the total deformation of concrete columns, either made of deformed rebar or SBPDN rebar. Based on the proposed method, the monotonic lateral resistance versus drift ratio relationships are investigated. In addition, to help structural engineers to obtain prompt and reliable capacity curve for the LQFA concrete columns, a simplified semi-empirical model is proposed. From analytical works described in this chapter, the following conclusions can be drawn.

1. Based on the assumption that the displacement due to slippage of tensile SBPDN rebar is primarily induced by the elongation of the tensile rebars within the loading stub or beam-column joint, the proposed analytical method to depict the capacity curve of LQFA concrete columns can give very good prediction of the experimental curves up to large deformation.

2. The displacement due to slippage of tensile steels varies along with the bond strength and confinement degree. For the columns with deformed rebars, the displacement due to slippage of tensile steels occupies 10% to 40% of the total displacement. The stronger the confinement by transverse steels, the smaller the displacement due to slippage. On the other hand, for the specimens reinforced by SBPDN rebars, the displacement induced by the slippage of tensile steels may reach

60% - 70% of the total one before SBPDN rebar yields. Confinement degree has only little influence on the displacement due to slippage because of the inherent low bond strength of SBPDN rebar.

3. The simple semi-empirical multi-linear model involves an important presumption that the peak lateral resistance of LQFA concrete columns will be reached when the tensile rebars commences yielding, which coincides with the experimental observations of the test specimens described in chapter two and chapter three of this thesis. The model can account for effects both of confinement by transverse steels and of slippage of tensile steels. The calculated capacity curves by the model agree satisfactorily well with the measured curves till large drift level.

4. Due to its simplicity and accuracy, the proposed model can help structural engineers to give a prompt and reliable prediction to the failure mode and ultimate drift level of LQFA concrete columns, promoting the application of LQFA concrete into building structures and contributing to the reduction of environmental burden by concrete industry.

（別紙１） 論文審査の結果の要旨

氏名	汪 俊華		
論文題目	Seismic Behavior and Evaluation of Concrete Members Made of A Large Quantity of Fly Ash （フライアッシュを大量配合したRC部材の耐震性能と評価方法）		
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要 旨

概要

1970年代から、靭性型鉄筋コンクリート（以下ＲＣと略す）構造は主要な耐震構造として、建築および土木構造物に活用されてきている。しかしながら、1995年の阪神淡路大震災、2008年の四川大地震、2011年の東日本大震災、および2016年の熊本地震の被害から、従前の靭性型構造物は、建築基準法で想定されている設計地震動に遭遇する際に、崩壊する確率が小さいものの、柱や梁などの構造部材に修復できないほどの大きな残留変形が残ること、基準の想定を超える強い地震動を受けうること、および連続する何回かの強い地震動に襲われるリスクがあることなど、重要な教訓が得られている。これらの教訓から、これからの耐震構造は、従前の地震時に崩壊しないという狭義的な「安全性」に加えて、強震による被災度合いが低い「復元性」と地震後の「修復性」を備えなければならないことは言うまでもない。また、21世紀にはいると、自然資源の再利用や節約を通して、自然環境への負荷の低減は建築・土木構造物に課したもう一つの時代の要請である。つまり、地震後の社会全体の早期復興と環境負荷低減に寄与できる建築・土木構造物には、安全性・復元性・修復性を包括した「レジリエンス性」と「環境親和性」の両方が求められる。

本論文では、想定外地震動や連続した強震動を受けても、地震に応答するときの挙動の「安定性」と地震後の「修復性」を併せ持ちながら、構造物の環境負荷の低減に寄与できる「レジリエント」な構造部材の開発を目指して、単調および繰り返し載荷実験によって、フライアッシュを大量に外割り混合した（LQFA）コンクリート柱の耐震特性と梁のせん断抵抗特性を明らかにしたうえ、LQFAコンクリートを用いたコンクリート部材の実用時に欠かせないせん断抵抗曲線と能力曲線のモデル化を行うことを目的とする。

本論文は６章からなっている。

第１章は序論であり、本研究の背景、既往の靭性型およびレジリエント構造部材の創出技術の研究現状を丹念にレビューしたうえ、主に火力発電所から排出される副産物であるフライアッシュを大量にコンクリートに外割り混合することと、付着強度の低い超高強度鉄筋（SBPDN）を主筋に用いることによって、レジリエンス性」と「環境親和性」を併せ持つＲＣ部材を実現させるという発想に至った経緯と、そのような部材の実用化時の課題を解説するとともに、本研究の目的と具体的な研究内容を述べている。

第２章では、高次モードの影響を受けて、単曲率変形に強いられる建築骨組み構造の最下層柱の耐震挙動を実験的に明らかにするため、スパイラルまたは薄肉鋼板で拘束された片持ち柱試験体を４体製作し、一定軸力下における繰り返し曲げせん断実験を行った。試験体は直径 250mm の円形柱で、それぞれに８本のSBPDN1275鉄筋または高強度異形鉄筋 USD685 を主筋として配置している。コンクリートは、水セメント比（65%）、単位水量（185kg/m³）および単位セメント量（285 kg/m³）をJASS５で規定されている最大値または最小値にして、細骨材のうちの 455 kg/m³ を第Ⅱ種フライアッシュで代替させたものを練り混ぜた。このようなコンクリートはLQFAコンクリートと称す。実験変数は主筋の付着強度と柱の横拘束方法の二つを取った。その結果、LQFAコンクリートの実験時材齢の圧縮強度は70MPaを超えて非常に高いが、適量

氏名	汪　俊華

のスパイラル筋による拘束とSBPDN鉄筋を用いたＲＣ円形柱は軸力比0.33（普通強度RC柱の上限値）の下でも部材角0.035radまで耐力が上昇し続けるというレジリエンス性を有し、さらに径厚比80程度の薄肉鋼管で拘束すれば、柱のレジリエンス性は0.05radまで向上することを明らかにした。一方、高い付着強度を持つUSD685異形鉄筋を用いた場合、柱の早期水平耐力が高いが、部材角が0.03rad前後に達した時点から鉄筋が降伏し始め、水平抵抗力が変形とともに低下し、せん断強度との逆転で大変形域でのせん断破壊を引き起こしてしまう恐れがあることを明らかにした。

第３章では、層抵抗機構を有する骨組み構造の任意階の柱の耐震挙動を実験的に明らかにするため、LQFAコンクリート、SBPDN1275鉄筋と鋼板拘束を併用した、逆対称変形下のＲＣ円形柱を４体製作し、繰り返し載荷実験を行った。試験体の断面直径は250mmでせん断スパン比が2.0で、柱に作用する軸力は軸力比が0.33となるように一定にした。実験変数は鋼板の形成方法、SBPDN鉄筋の加力スタブ内の定着長さ、および柱反曲点近傍における主筋の付着定着板の有無の三つを取った。径厚比が156の円形鋼板は市販されていないので、平板を半円に折り曲げたうえ、ボルトとナットによる結合と溶接の二つの方法で鋼管を形成した。実験結果より、ナットとボルトで結合した円形鋼管は溶接鋼管とほぼ同等の拘束効果を有し、高軸力下における柱に0.05radまでのレジリエンス性を確保できること、溶接極薄肉鋼板は大変形域では溶接部が破断し、柱をせん断破壊させてしまう恐れがあること、双曲率変形下の柱の反曲近傍で主筋の定着板を設けなければ、柱のレジリエンス性が0.05radから0.035radまで低下することなどを明らかにした。

第４章では、LQFAコンクリートの圧縮強度が70MPaを超えて、それを用いた柱はせん断破壊しにくいことを踏まえ、LQFAコンクリートを用いた角形部材の性能評価にも適用できるような、包括的なLQFAコンクリート部材のせん断挙動を追跡するための「せん断抵抗曲線」を開発することを目的に、LQFAコンクリートを用いた矩形梁を20体製作して、単調曲げせん断実験を行った。梁の断面は150mm×250mmで、実験変数はせん断スパン比と引張鉄筋比の二つを取った。実験結果と梁のせん断破壊斜面における力の釣合条件に基づいて、LQFAコンクリート部材の終局せん断耐力の算定式およびせん断抵抗力と部材角の関係モデルを構築した。さらに、そのせん断抵抗曲線はLQFAコンクリート梁のみならず第２章と第３章で述べた柱のせん断耐力の変遷を比較的精度よく評価できることを明らかにした。

第５章では、第２章と第３章で述べた実験結果、現在の保有耐力算定法よりも性能基盤型設計法の方がSBPDN鉄筋を用いた柱の耐震設計に適していることを踏まえ、SBPDN鉄筋の付着による柱変形への影響を定着部内での鉄筋の総伸び量をもって近似できると仮定したうえ、柱の能力曲線を簡便に解析するための方法を提案し、その解析方法の妥当性と精度を検証した。さらに、この解析手法による数値実験の結果と実験結果に基づいて、性能基盤型耐震設計に不可欠なLQFAコンクリート柱の能力曲線モデルを構築した。第２章と第３章で述べた実験結果と比較した結果、本章で構築したモデルはレジリエントなLQFA円形RC柱の実験結果を比較的精度よく評価できることが明らかになった。

最後に、第６章では、以上各章の研究成果を総括して、本研究の結論とした。また、本論で開発した省エネ型のレジリエントなＲＣ円形柱などの実用時における今後の研究課題を示した。

以上で述べたように、本研究は地震時の安全性、地震後の復元性・修復性、および環境負荷の低減に寄与できる「環境親和性」を併せ持つ、新しいレジリエントな耐震構造部材について、そのような部材の耐震挙動および実用時に必要不可欠なせん断抵抗曲線と能力曲線の構築を研究したものであり、次世代の新しい耐震構造部材の性能と設計法について重要な知見を得たものとして価値ある集積である。提出された論文は工学研究科学位論文評価基準を満たしており、学位申請者の汪俊華は、博士（学術）の学位を得る資格があると認める。