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MULTILEVEL ORGANIZATIONAL CHANGE READINESS: TOWARDS COMPREHENSIVE VIEW IN DEVELOPING COUNTRIES CONTEXT

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Abstract

Majority of existing literature on change readiness provide a fragmented single level examination. Recently, some studies tried to incorporate multilevel concept in change readiness, however they still neglected institutional level readiness. For appropriate intervention, change agents need to consider all levels of change readiness. Following extensive literature on organizational change readiness at individual level and organization level, this conceptual paper uses institutional theory to provide broader conceptualization on multilevel change readiness. Institutional theory viewpoint provides to look change readiness from wider perspective. Since organizations are multilevel in nature, thus multilevel change readiness examination provides comprehensive understanding. In addition to the traditional individual and organizational level readiness, using institutional theory, we propose institutional level readiness should also be a critical predictor for the success of organizational change particularly in developing countries. Thus, the study proposes some propositions showing how these concepts relate to each other. Finally, the study suggests some practical implications for the leaders.

Keywords: multilevel change readiness, individual level, organizational level, institutional level

Introduction

Despite the high failure rate of organizational changes, currently it is an unavoidable practice (Smith, 2002). Around half of all organizational change failures occur because change agents failed to establish sufficient readiness to change (Kotter, 1995). Unlike dealing with resistance, change readiness is a proactive effort taken by change agent to prepare organizational members to increase the likelihood of success rate (Bernerth, 2004). Organizational readiness is a strong predictor for the success of change (Armenakis, Harris, & Mossholder, 1993). When organizational readiness is high, organizational members are more likely to accept change, exhibit greater persistence and effort in the face of challenges during change implementation (Weiner, 2009).

Regardless of the degree of interest in change readiness, however, we identify two major limitations that currently restrains our understanding on change readiness concept. Despite the suggestion to use multilevel approach for change readiness (Weiner, 2009) and the fact that organization is an integrative multilevel system. Majority of the previous literature on change readiness focused on a single level analysis with some exceptions (Rafferty, Jimmieson, & Armenakis, 2013; Vakola, 2013; Weiner, 2009) that conceptualized multilevel readiness as an individual and collective level change readiness. Nevertheless, this conceptualization also neglected external institutional readiness. Due to the complexity of organizational change, the success of change not only bounded within the organization but also depends on external stakeholders such as suppliers, customers, competitors and governmental agencies (Krell, Matook, & Rohde, 2016; Shah, Irani, & Sharif, 2017; Teo, Wei, & Benbasat, 2003). Remarkably, large scale changes require information sharing beyond organizational level across multiple organizations and agencies in the environment (Sherer, Meyerhoefer, & Peng, 2016).

Moreover, majority of readiness studies examined developed countries context (Holten & Brenner, 2015; Weiner, 2009). Hence, they neglected the external stakeholder's influence on organizational change outcomes. Given organizational resource limitation in the developing countries, organizations are quite dependent on external stakeholders (Osakwe, Chovan-cova, & Agu, 2015). Thus, organizational changes notably driven by the rule of legitimacy with their environment. Due to the high reliance on their environment, they are even less concerned about the benefits of change (Kurnia, Choudrie, Mahbubur, & Alzougool, 2015). However, mainly organizational changes in the developed countries are driven by a rationalistic and deterministic orientation guided by goals of technical efficiency and performance (Shah et al., 2017). Therefore, due to such differences between organizations in developing and developed countries, research findings obtained from developed countries cannot be applied directly to developing countries (Spinelli, Paul Jones, Dyerson, & Harindranath, 2013). Thus, we can argue that institutional level readiness has significant impact in developing countries. This study used institutional theory to understand the environmental level of readiness.

Institutional Theory

Institutional theory highlights on the wider aspects of social structure, which can better explain the external stakeholders' relationship with the organization. It emphasizes that institutional rules such as contracts, government regulations, nonbinding industry norms and routines, established as authoritative guidelines for social behavior (DiMaggio & Powell, 1983; Tsai, Lai, & Hsu, 2013). Institutional theory states that firms seek to achieve legitimacy by obeying political and institutional rules in order to succeed and survive (Krell et al., 2016; Mignerat & Rivard, 2009). For example, previous study found that suppliers had to be socially acceptable to secure status within the industry (Tsai et al., 2013).

Researchers conceptualized institutional pressures as coercive, mimetic, and normative pressure (DiMaggio & Powell, 1983). All together referred to as isomorphic pressures, because initially different firms in the same environment engaged in similar activities exposed to the same institutional pressure, which make them more similar over time (DiMaggio & Powell, 1983; Tsai et al., 2013).

Mimetic pressures emerged from behavioral uncertainty to provide a solution for unknown problem (DiMaggio & Powell, 1983; Krell et al., 2016; Sherer et al., 2016; Teo et al., 2003). Regardless of the efficiency outcomes, an organization imitates the practices of other structurally equivalent and successful organizations in order to get legitimacy (DiMaggio & Powell, 1983). The structurally equivalent organization referred as organizations occupying a similar economic network position in the same industry which produce similar products, share similar customers, suppliers, and experience similar constraints (Burt, 1987; Teo et al., 2003).

Normative pressure referred as the pressure generated from norms, standards of the institutions such as professional or industry associations. It is the most often practiced which favored the firm and considered as acceptable standard by the environment (Sherer et al., 2016). Early adopters push or persuade other organizations with business ties to them such as suppliers, and customers to follow their practice for the convenient communication (Teo et al., 2003).

Coercive pressures generated from resource dominant partners such as customers, suppliers, governmental agencies or parent organizations. Unlike normative pressure, such dominant partners have the power to impose sanction on noncompliance organizations (DiMaggio & Powell, 1983; Sherer et al., 2016). For example, a firm should comply with the government regulations to sustain (Krell et al., 2016). Thus, the resource dependent organizations are likely to exhibit similar structural features such as formal policies, organizational models, and programs with the resource dominant organization to get acceptance and build a smooth relation (DiMaggio & Powell, 1983; Teo et al., 2003).

Organizational Change in Developing Countries

Prior research noted that inadequate infrastructure, governmental policies, and lack of information technology, seriously affect organizational changes in developing countries (Huang & Palvia, 2001). Hence, organizations are highly dependent on external factors (Kurnia et al., 2015). They need support from government and partner in terms of friendly legislation and resource provision to achieve success (Osakwe et al., 2015). In contrast, studies from the developed countries neglected external context such as infrastructure, governmental policies, and information technology since these may not have their problem (Holten & Brenner, 2015; Weiner, 2009).

Individual Level Readiness

Individual level readiness defined as an individual's appraisal about him/herself, organizational capacity to handle a change, and the benefits that the organization and members may get from the change (Armenakis et al., 1993; Holt, Armenakis, Harris, & Feild, 2015). In addition, it was conceptualized as organizational members' cognitively and emotionally inclined to accept, embrace, and implement the change (Armenakis et al., 1993; Holt, Helfrich, Hall, & Weiner, 2009).

Organizational Level Readiness

Researchers adopted individual level readiness (Armenakis et al., 1993) to describe organizational level readiness (Holt et al., 2009; Rafferty et al., 2013; Weiner, 2009). Holt and his colleagues' defined organizational readiness as organizational members' shared cognitive and emotional inclination to accept, embrace, and implement a particular change (Holt et al., 2009). Weiner (2009) also defined organizational readiness as a psychological state in which organizational members collective change commitment and collective change efficacy to implement organizational change. Another study conceptualized organizational readiness as a shared perceptions and beliefs that include need for change, collective change efficacy, collective change benefit and collective capacity for the change (Vakola, 2013).

Institutional Level Readiness

Institutions referred as collection of different stakeholders such as customers, suppliers, competitors and governmental agencies located in the same environment (DiMaggio & Powell, 1983). Such stakeholders influence organizational change process and being influenced at the same time (White, 2000). Firms in the same environment compute with another equivalent structure firms that is having the same customers, suppliers and equivalent products (Burt, 1987). Thus, particularly in the developing countries the successful outcome of organizational change significantly determined by good working relationship and communication with external stakeholders (Krell et al., 2016; Shah et al., 2017; Teo et al., 2003).

Multilevel Change Readiness

Organizations are inherently multilevel systems including individuals, and groups (Costa et al., 2013; Klein & Kozlowski, 2000) which needs multilevel analysis to understand the change readiness comprehensively. However, the common misconception in the previous researchers is the aggregation of individual level data to represent the organization level constructs (Hitt, Beamish, Jackson, & Mathieu, 2007) and generalizing a conclusion for an organizational level analysis (Bouckenooghe, 2010). Importantly, the relation embraces at the lower level does not grant the same relation at higher levels (Ostroff, 1993). Individuals having high readiness may not have the same high readiness at collective level (Weiner, 2009). The individual performance ratings may not necessarily lead to an increase in team performance; team members may perform well as individuals, but function poorly as a united team. Thus, the procedures commonly used to justify aggregation provides an assessment of the lower level data are homogeneous within the organization and the constructs in the lower level are correspondingly homologous to the constructs of higher level (Klein & Kozlowski, 2000). Hence, we propose the following:

P1: Organizations having a higher proportion of individually ready employees to change would not necessarily have higher level of organizational change readiness.

Organizational level readiness studies argued that concerning overall organizational change, organizational level analysis better predicts for adequate investigation (Weiner, 2009). However, in line with collective assessment, examining individual readiness level is also crucial because the change is initiated and implemented through individuals as a result each individual should be ready for the change (Holt et al., 2015).

Researchers suggested multilevel study for change readiness to get deep insight (Bouckenooghe, 2010). Multilevel study makes the change agent to understand the cross level communication in the organization that is how phenomena at different levels are linked top down or bottom up. Top down approaches refer the effect of higher-level factors on lower level factors. For example, organizational culture influences individual level feelings. Bottom up mechanisms explain how the individual level achievement contribute to the organizational level achievement (Rousseau, Aguinis, Boyd, Pierce, & Short, 2011). However, research suggested top down relation has more impact than upward processes, proposing that the larger context is more likely to influence lower context (Costa et al., 2013; DiMaggio & Powell, 1983).

P2: In multilevel change readiness, the organization level factors will have more influence on individual level factors than the reverse.

Furthermore, in the developing countries where firms are too much dependence on their environment, and less concerned about the benefits of change (Kurnia et al., 2015), their change initiation are largely driven by the institutional legitimacy. Organizational change readiness is determined with the top down approach by political and institutional legitimacy in order to succeed and survive in a social network (Krell et al., 2016; Mignerat & Rivard, 2009). Previous study found that suppliers had to be socially acceptable to secure status within the industry (Tsai et al., 2013). As a conclusion, firms need to conform to the rules and belief in the institutional environment to gain legitimacy. Their existence depends on the alignment with the institutional environment (DiMaggio & Powell, 1983).

P3: In multilevel change readiness, institutional level readiness have more influence on organization level readiness than the reverse.

Conclusion

Despite several suggestions to do multilevel study, scholars on organizational change readiness mainly focused on a single level study. Thus, this study proposes a multilevel readiness concept to examine the overall insight of readiness and their interaction effect across levels.

Multilevel change readiness studies from developed countries were restricted to individual and organizational level change readiness because external institutions are less significant to affect the change process. However, in developing country, organizations are highly dependent on external institutions. Thus, scholars need to examine institutional level readiness along with individual and organizational level readiness when they conduct change readiness studies in the developing countries.

Finally, leaders should aware about multilevel readiness prior to organizational change. Knowing the extent of multilevel readiness may benefit the change agents to take corrective measures ahead of organizational change implementation.

Leaders can enhance individual and collective readiness by improving capability of organizational members. Organization can also improve relations with other organizations and governmental agencies to increase institutional level readiness.

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VALUE CHAIN PERSPECTIVE TO MEASURE KEY SUCCESS FACTORS IN SOCIAL HOUSING IN TAIWAN

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Abstract

This article aims to use a value chain perspective to measure key success factors in social housing using the analytic hierarchy process (AHP). Scholars, experts, and industrial professionals in the housing field, such as those in building construction, welfare supporting institutions, real estate, as well as central and local government officials, were asked to respond to questionnaires. AHP is applied to 38 valid questionnaires to analyze the opinions of university, government, and industry experts on the key success factors that influence social housing construction to evaluate the weight of the criteria at each hierarchy. This study found that the most important key factors are hierarchy of law and policy, particularly affordable housing. The policy is in accordance with the needs of the market, such as deregulation and rental subsidy.

Keywords: social housing, value chain, analytic hierarchy process, key success factors

Introduction

In 2016, the housing supply rate in Taiwan exceeded 100% and the vacancy rate reached as high as 13.9%. In

2017, house price affordability was 9.24 times higher than the average income of a Taiwanese citizen. The problem is that disadvantaged people are unable to buy or borrow money to build their houses. Renting or paying for inexpensive housing is even more difficult. Therefore, to implement the goal of residential justice, the government of Taiwan has conducted various types of housing policies, such as rental subsidy, interest subsidies for residential loans to purchase and repair houses, building residence, and others. In 2011, the Taiwan government enacted the Housing Law. The housing policy has been changed from national houses built by the government to social housing that is only rented and unsold. Direct build or build– operate–transfer mode is adopted to encourage the rebuilding of unused structures. In addition, the method of renting and unselling is used to help disadvantaged people who are unable to obtain good living spaces due to lack of economic capacity.

Social housing is an important policy in all countries. For example, near the end of the 19th century, Britain became aware of the gravity of the housing problem of laborers and low-income families. At present, local governments and housing associations are responsible for managing this problem. The rent is lower than the market price. Social housing is mainly for elderly people, single parents, low-income households, and new couples without savings. The Netherlands is currently the country with the highest proportion of social housing in the world. The government, as a real estate developer, promotes the construction of social housing and targets the elderly, people with limb disorders, cultural minorities, people who live in cars, the homeless, and asylum seekers as the main recipients. In East Asia, Japan is the first country to develop public housing and focuses on the economically and socially disadvantaged people as its main recipients. Singapore strongly controls the housing market such that 80% of the houses belong to the government, which formulates the subsidy policy for constructing or renting housing and development board flats and the appropriate housing fund system. The government aims to encourage citizens to rent or purchase.

In 2011, the Social Housing Alliance pointed out the proportion of social housing to the total housing in various countries, namely, 32% in the Netherlands, 18.2% in the United Kingdom, 19% in Denmark, 18% in Finland, 18% in Sweden, 6.2% in the United States, 6.06% in Japan, 30% in Hong Kong, 8.7% in Singapore, and 4.6% in South Korea. In Taiwan, social housing is still at the initial stage. At present, the Taiwan government aims to promote policies, such as those for the benefit of the elderly and youth, to meet the demands of the population at varying economic levels. The type of housing that meets the definition of social housing in Taiwan accounts for only 0.08% of the total national housing. Social housing in Taiwan is inadequate and lagging far behind the global standard. Therefore, this paper aims to realize the key success factors (KSFs) of social housing and provide the governmental departments and related industries with a reference. Porter (1985) introduced the concept of value chain, which is a basic tool that enterprises can use as a source of advantage. Nicovich et al. (2007) also posited that the value chain could be used to evaluate the interdependence of all items and their linkages on the upper and lower reaches of the enterprise.

Furthermore, this paper aims to discuss the KSFs of social housing from the concept of value chain to formulate feasible strategies and supporting measures for the government sectors and future reference for related industries. Saaty (1999) proposed that the KSFs could adopt the aanalytic hierarchy process (AHP), a method through which the opinions of scholars, experts, and participants are collected via group discussion to simplify a complex problem evaluation system into a concise hierarchical one. Then, an expert questionnaire is used to calculate the contribution or priority of each hierarchy.

Concept of Value Chain and Hierarchical Structure of Social Housing

Porter (1985) believes that the value chain refers to a series of value creation activities of enterprises to create valuable products or services for customers from suppliers of raw materials in the upstream to the final buyers of the products in the downstream. The value chain decomposes the enterprises according to their strategically related activities to understand the cost characteristics of an enterprise and existing and potential sources of differentiation.

In addition, they can obtain the best competitive advantages in important activities because they can implement these strategies at a lower cost or higher efficiency than their opponents. Value activity can be divided into nine types according to their technical features or strategic characteristics. Additionally, according to the nature of its value creation, these types of general value activities can be summarized into two activities, namely, basic and supporting. The basic activities consist of production, marketing, transportation, and after-sale services of the products and other business activities, such as the following value activities, namely, incoming materials and logistics, production operation, warehousing and transportation, sales and marketing, and after-sales services. Supporting activities refer to input activities that can facilitate the smooth operation of major activities, such as the following value activities, namely, enterprise infrastructure, technology development, human resource management, and procurement.

In this paper, to determine the KSFs of social housing, the basic activities are divided into site selection, land assessment, capital operation pattern, and space integration planning and other measurement dimensions. Meanwhile, supporting activities were divided into regulations and policies, business strategy, and other dimensions. Table 1. shows the three- hierarchy assessment criteria, which are described as follows:

Main activities

A. Site selection
(A) Local residents' sense of identity: identification of local residents should be obtained through communication and coordination before construction to avoid strong opposition from surrounding residents regarding the construction of social housing.
(B) Housing safety: social housing should be safe and ideal in terms of the external environment (community

safety) and internal facilities (fire-fighting and disaster prevention equipment) so that the residents can live in peace and security.
(C) Traffic convenience: integrity of the traffic and transportation system around the social housing area.
(D) Living function: extent of living function provided by the neighborhood around the social housing area.
(E) Integrity of public facilities: setting of relevant facilities, such as education, leisure, and medical care, for public construction around the social housing area.

B. Land use assessment
(A) Selection of site section: choice of land for social housing, which should be in accordance with the regional and urban plans.
(B) Uniqueness of local resources: diversity and uniqueness of resources that can be provided within the area.
(C) Benefits from a developed entity: appropriateness of the development of social housing and actual benefits from it in the future.
(D) Public land without buildings and crops: public land released by the state does not have structures and plants on it.
(E) Land cost: Land price affects the fluctuation of regionally expropriated price to affect the funds required for construction.

C. Capital operation pattern
(A) Fundraising and reward: raising the willingness of investors to invest in the con social housing through a variety of incentives to raise funds.
(B) Feasibility of market demand: market demand influences the willingness and capital investment of investors.
(C) Civil participation in public construction: traditional public construction by the government is released to the people for building and operation to improve efficiency and public quality through private capital, creativity, and management technology.
(D) Private finance initiative (PFI): a method of providing financial support to public services for the people. That is, the public sector does not have to invest in the construction of public facilities. Instead, it purchases services every year from a private sector that owns the asset in a contract. Doing so will ease the financial burden of the government for the construction of public facilities through the capital and operation efficiency of private sectors.
(E) Fund operation management: Based on the operation of fund circulating investment, earnings are used to cover the loss of funds during the investment process to achieve balance between revenue and expenditure and maintain the stability of management operation.

D. Spatial integration planning
(A) Multi-integration development: residents must unite at a certain point and multi-integration development with neighboring residential buildings must be adopted to moderately disperse balance demand and prevent disadvantaged centralization and slum areas.
(B) Public space planning and design: a neighborhood foundation strategy is adopted for regional planning and design of public housing to facilitate the development of the community.
(C) Overall maintenance of residential renewal: repair, refurbishment, reconstruction, and rebuilding of old social houses.

(D) Type of rental house and space configuration: size and internal pattern planning of social houses.
(E) Space allocation of barrier-free facilities: construction of social housing aims to build barrier-free humanized residence for citizens with special physical and mental functions.

Support activities

A. Regulations and policies
(A) Deregulation: The Social Housing Law should be considered as a special law and based on a system in which this law is superior to ordinary laws. The difficult implementation of social housing policies brought by the limitation on the applications of the regulations is prevented.
(B) Housing assessment system: set of withdrawal mechanism for housing assessment established in accordance with the current condition of environmental demand to implement the sustainable management of social housing.
(C) Policy planning that conforms to market supply and demand: social housing policy should a priori determine the solutions to the demands of the disadvantaged population (economic, social, or stage care recipients or repeating demand households) and amount of housing required for this population.
(D) Rent subsidy: a fair, reasonable, and long workable housing subsidy system should be established in accordance with the demands of the disadvantaged population to implement living justice, which is the primary goal.
(E) Affordable housing: affordable housing policy suitable for home life based on various types of rental house and subsidy systems by adopting measures that suit local conditions.

B. Business strategy
(A) Reasonable renting price: reasonable charge is an important factor that prevents the disadvantaged population from obtaining social housing.
(B) Ability of holding market demand trend: ability to master the demand trend of the social housing market.
(C) Sustainable management of social housing: the government proposes social welfare supporting measures to make social housing a sustainable and cyclical residential public investment.
(D) Cooperation with nongovernmental organizations: a special organization is established through cooperation with civil charities and non-profit organizations, which are responsible for the construction and management of social housing.
(E) Appointment of administrative legal officer for social housing: a public legal officer is appointed in accordance with the law by central-level target-business competent authorities besides the national autonomous community.

Sample description and empirical analysis

(1) Sample description.

The survey respondents were experts and scholars in the field, and central and local officials, who had knowledge and expertise in issues such as building construction industry, welfare supporting institution, and real estate guilds. After confirmation over the telephone, the questionnaires were mailed or delivered personally. Robbins (1994) indicates that the number of experts at least should be ideally 5 to 7 for the issues that require collective decisions. Among the total number of questionnaires, 15 were sent by mail and 28 were delivered personally. A total of 43 questionnaires were sent out whereas 38 were returned. Thus, the recovery rate is 88.4%. In terms of sample distribution, 13 questionnaires surveyed those from the industry (0.34%), 14 from governmental units (0.37%), and 11 from the group of scholars and experts (0.29%).

(2) Empirical analysis.

This method was utilized in the study on contingency planning for the US Department of Defense in 1971. It is mainly used in case of uncertainty, that is, decision making with multiple evaluation criteria, to individually simplify originally complex problems. AHP posits that, in the face of the appropriate choice of plans, a set of criteria is accorded to the assessment of various alternative plans to determine the degree and priority of plans and establish a hierarchical structure that affects one another. Each expert is invited to conduct a paired comparison of the importance of all factors. After establishing the comparison matrix, the eigenvalues and eigenvectors are calculated. Finally, consistency of the maximum eigenvector is verified while all assessment criteria are used to rank the relative weights to screen out the selection method for the assessment criteria on the decision-making problem.

This paper aims to evaluate the weight of the criteria at each hierarchy and compare the difference in all weights in various dimensions based on the opinions of the production– university– government experts on the KSFs in social housing by means of AHP. Table 2 shows the results. The table shows that for the first-hierarchy index, the production– university– government experts reveal that "main activities" are of utmost importance, followed by supporting activities. For the main activity dimension at the second hierarchy, site selection is a key factor with the highest degree of importance, followed by capital operation pattern and space integration planning. Land assessment is the most unimportant of the factors. For the supporting activity dimension at the second hierarchy, the degree of importance of regulations and policies is the highest, followed by business strategy. The third- hierarchic assessment criteria are classified in six dimensions, namely, site selection, land assessment, capital operation pattern, space integration planning, regulations and policies, and business strategy. According to Table 2, good living function has the highest importance under site selection, followed by housing safety. For land assessment, site selection has the highest degree of importance, followed by land cost. For capital operation pattern, feasibility of market demand has the highest degree of importance, followed by fund operation management. For space integration planning, public space planning and design has the highest degree of importance, followed by type of rental house and space configuration. For regulations and policies, affordable housing has the highest degree of importance, followed by policy planning conforming to market supply and demand. For business strategy, reasonable renting price has the highest degree of importance, which is the most important key factor, followed by sustainable operation of social housing.

In terms of individual projects, we found that the most important key factors are regulations and policies, particularly affordable housing, policy planning conforming to market supply and demand, deregulation, and rent subsidy and other factors. The government establishes an interdepartmental and cross-level Promotion Committee of Social Housing, which is composed of related governmental departments, experts, scholars, enterprises, and civil opinion leaders. This paper proposes that the relevant decrees be deregulated during promotion to eliminate the deficiency of existing regulations.

Conclusions and Suggestions

Social housing is an emerging concept in Taiwan. "Making Homes Affordable" has long been the core principle of the government's housing policy. In recent years, several government departments have launched policy-oriented residential plans to meet the housing needs of various economic sectors. From a comprehensive view of the government's multiple housing policies, social housing is indeed appropriate and necessary. Promoting social housing is not only for the benefit of the disadvantaged population but is also intended to deal with the inefficiency of social assistance. Is social housing merely a residential issue or a problem of urban and land development? Is it the problem of market coexistence and system reform? Is it a problem of operating management and social relations? Moreover, is it a problem of the common participation of residents in the reconstruction and creation of the value of urban use?

This paper raises the following conclusions and suggestions:

(1) The demand side of social housing should be established to ensure a balance between supply and demand.

The government has actively promoted social housing since the promulgation and implementation of the housing law in December 2012.

Table 1. Hierarchy index framework for key success factor assessment of social housing

	Hierarchy		
	First	Second	Third
Key success factors in social housing	Main activities	Site selection	Local residents' sense of identity Housing safety Traffic convenience Living function Soundness of public facilities
		Land assessment	Selection of site section Uniqueness of local resources Benefits from developed entity Public land without buildings and crops Land cost
		Capital operation pattern	Fundraising and reward Feasibility of market demand Civil participation in public construction Private finance initiative

			Fund operation management
		Space integration planning	Multi-integration development mode Public space planning and design Overall maintenance of residential renewal Type of rental house and space configuration Space allocation of barrier-free facilities
	Supporting activities	Regulations and policies	Deregulation Housing assessment system Policy planning conforming to market supply and demand Rent subsidy Affordable housing
		Business strategy	Reasonable renting price Ability to hold market demand trend Sustainable management of social housing Cooperation with nongovernmental organizations Appointment of administrative legal officer for social housing

Table 2. Weight of key success factors in social housing

	Hierarchy			
Goal	First	Second	Third (A, B)	Total average (ranking)
Key success factor in social housing	Main activities (0.646,1)	Site selection (0.420,1)	Local residents' sense of identity (0.196,4)	0.082 (9)
			Housing safety (0.207,2)	0.087 (7)
			Traffic convenience (0.202,3)	0.085 (8)
			Living function (0.257,1)	0.108 (5)
			Soundness of public facilities (0.152,5)	0.064 (14)
		Land assessment (0.165,4)	Selection of site section (0.261,1)	0.043 (19)
			Uniqueness of local resources (0.111,5)	0.018 (30)
			Benefits from developed entity (0.187,4)	0.031 (28)
			Public land without buildings and crops (0.192,3)	0.032 (26)
			Land cost (0.249,2)	0.041 (21)

	Capital operation pattern (0.225,2)	Fundraising and reward (0.197,3)	0.044 (18)
		Feasibility of market demand (0.290,2)	0.065 (13)
		Civil participation in public construction (0.161,4)	0.036 (25)
		Private finance initiative (0.138,5)	0.031 (28)
		Fund operation management (0.215,2)	0.048 (17)
	Space integration planning (0.190,5)	Multi-integration development mode (0.198,4)	0.038 (23)
		Public space planning and design (0.219,1)	0.042 (20)
		Overall maintenance of residential renewal (0.202,3)	0.038 (23)
		Type of rental house and space configuration (0.211,2)	0.040 (22)
		Space allocation of barrier-free facilities (0.170,5)	0.032 (26)
Supporting activities (0.354,2)	Regulations and policies (0.643,1)	Deregulation (0.213,3)	0.137 (3)
		Housing assessment system (0.121,5)	0.078 (10)
		Policy planning that conforms to market supply and demand (0.214,2)	0.138 (2)
		Rent subsidy (0.173,4)	0.111 (4)
		Affordable housing (0.279,1)	0.179 (1)
	Business strategy (0.357,2)	Reasonable renting price (0.259,1)	0.092 (6)
		Ability of holding market demand trend (0.212,3)	0.076 (11)
		Sustainable management of social housing (0.213,2)	0.076 (11)
		Cooperation with nongovernmental organizations (0.161,4)	0.057 (15)
		Appointment of administrative legal officer for social housing (0.155,5)	0.055 (16)

Note: (A, B) refers to weight and ranking, respectively.
Data source: Data obtained by authors

The government believes that under the pressure of expensive house construction and rent, the housing needs of the socially disadvantaged population is not guaranteed. The government has high ideals and ambitions, but its current efforts are sporadic and inadequate to promote social housing. In addition, it has not developed the demand side through an overall planning approach. Therefore, planning and designing a general residential space that meets the aforementioned requirements according to housing demand, achieving a balance between supply and demand in the social housing market, and implementing residential justice are the most important tasks for the government to promote social housing. Social housing should be developed in multiple modes.

Social housing is a part of the pluralistic function of the housing policy in a country. The social housing system is gradually established by the government to assist disadvantaged citizens in solving their residential problems. Therefore, government departments should set up a basic living standard for social housing and assess it using multiple factors, such as site selection, capital operation pattern, space integration planning, and land use assessment, to adopt measures that suit the local conditions and ensure the successful construction of social housing.

Social housing involves a consideration of people's needs. The local government must consider the income and living conditions of the disadvantaged population to construct a classification system and reasonable burden level to ensure social fairness. Therefore, with full communication and coordination, the residents must be mixed at a certain proportion. In addition, the neighborhood foundation strategy should be formulated in the planning and design of public housing. The development of multiple structures should be adopted in coordination with neighboring houses to ensure that social housing areas become friendly communities. Public facilities in the community should be provided to adjacent residents to promote interaction between residents of varying backgrounds and communities so that social stereotypes can be eliminated. Thus, disadvantaged centralization and slum areas can be prevented.

(2) Tax relief and investment incentive scheme to encourage private enterprises to invest.

The tax system has been reformed to curb soaring prices of housing and consequently to achieve residential justice. It has gradually developed a mainstream appeal to people from of all walks of life. However, the construction of public facilities has unique investment characteristics, such as large investment scale, a longer period of investment compared to ordinary private investment, and high completion risk. In addition, construction involves public interest, complex political and economic interaction, and regulatory risk. These characteristics not only affect the feasibility of the investment but also have a far-reaching impact on financial planning and financing. Therefore, the government should attach importance to public construction financing, provide private institutions with interest-free subsidy, and grant medium- and long-term loans through financial institutions or special funds to reduce financial costs and refinancing risk, thereby encouraging private enterprises to participate in the investment.

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IMPROVED ANALYTICAL SOLUTIONS FOR HYDRAULIC GRADIENT DISTRIBUTIONS OF A SPECIMEN IN A CONSOLIDATION TEST

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Abstract

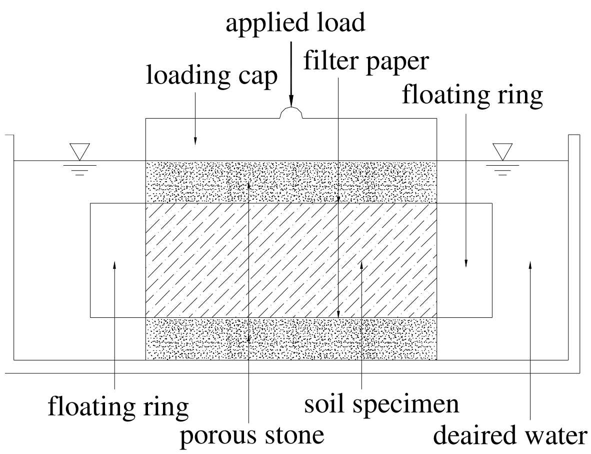
Mitchell pioneered analytical solutions for the hydraulic gradient distributions of a test specimen that undergoes a consolidation test in 1976. Such solutions are valuable and helpful to soil engineers in precisely understanding the difference between the hydraulic gradients of a specimen and an in situ stratum. However, Mitchell used a compressibility ratio, R, equal to zero, and a stiffness for the pore water pressure measurement system, η, equal to infinity in order to determine the solutions. Thus, Mitchell's solutions could not describe the real behavior of soil consolidation. Accordingly, this work seeks to formulate equations for conditions where both R and η correspond to real conditions. The solutions of this work tend to be more realistic and useful than those in the literature.

Keywords: consolidation, compressibility, stiffness, hydraulic gradient.

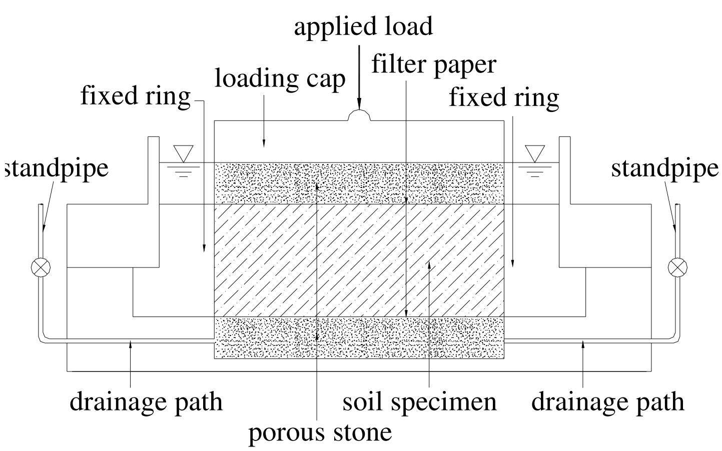
Editor's Note: This article is in single column format to facilitate ease of reading the complex formulas.

Introduction

Traditional consolidation tests, using either a floating ring or fixed ring (Figure 1), are normally performed without measuring the pore water pressure. Therefore, water can be drained from one or both sides of a specimen (ASTM, 1997). However, when the variation of excess pore water pressure needs to be determined, a specialized consolidation test must be undertaken. When the measurement system is connected to the bottom of a specimen (Figure 2), water can only be drained from the top (Perloff, Johnson and Degroff, 1965).



(a) floating ring



(b) fixed ring

Figure 1. Schematic diagrams of rings for consolidation tests
(U.S. Army Corps of Engineers, 1970)

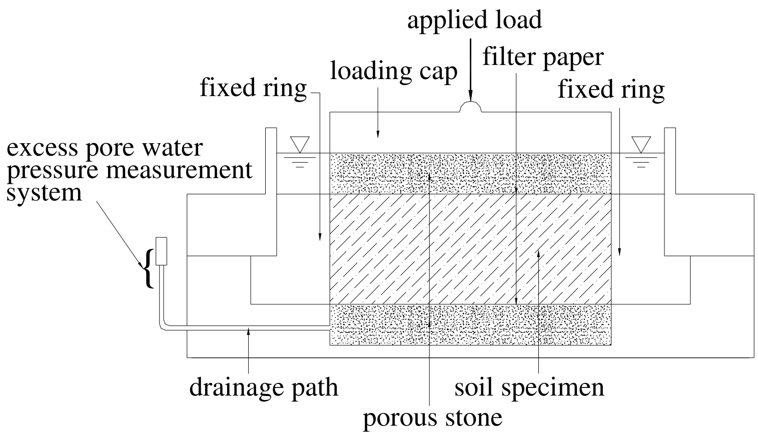


Figure 2. Schematic diagram of the ring for a consolidation test with excess pore water pressure measurements (Modified from Figure 1b)

For a traditional consolidation test, Taylor (1948) presented analytical solutions for the change in excess pore water pressure, u_e, with an increase in the time factor, T, and the depth, z, of a specimen, using the Terzaghi one-dimensional consolidation equation (Terzaghi, 1925, 1943). Although geotechnical engineers commonly use such solutions, several investigators have found a low rate of consolidation (Cowley et al. 1975; Crank and Nicholson 1947; Hyde and Leach 1975; McVag et al. 1986). The above-mentioned investigators pointed out that the reasons for the low rate include the anisotropy and stratification of the soils. The rate of consolidation has also been found to be influenced by the effective stresses changing with the applied load as a function of time (Abuel-Naga and Pender, 2012; Barron, 1948; Fox, 1996; Duncan, 1993; Dubin and Moulin, 1985; Elnaggak and Krizek, 1973; Hansbo, 2003; Olson, 1977; Xie, et al., 2012; Zhu and Yin, 2001). Apart from the above-mentioned reasons, another major cause of the low rate of consolidation is the assumption of the incompressibility of water (Hsu and Chang, 1993).

Perloff, Nair, and Smith (1965) developed an analytical solution for excess pore water pressure distribution by taking into account the stiffness of the measurement system in a special consolidation test. Notably, they also adopted the Terzaghi one-dimensional consolidation equation.

Mitchell (1976) determined analytical solutions, based on the solutions of Taylor (1948), for the distribution of the hydraulic gradient, i, in a consolidation test specimen. When utilizing the compressibility ratio, R, defined as equal to the compressibility of water, c_w, divided by the coefficient of compressibility of the so-called 'saturated soils', a_v (Hsu and Chang, 1993), and the stiffness of the pore water pressure measurement system, η (Perloff, Nair, K. and Smith, 1965), Solutions of Mitchell (1976) have the inherent problem of the adoption of an R of zero and a η of infinity.

The compressibility of pure water without dissolved air is very close to zero, so its effect on the solutions is sufficiently small and can be neglected. However, the situation changes greatly when even a small amount of dissolved air is present in the pore water. One reference (International Critical Table, 1928) reports that the content of dissolved air was as high as 1.8% by volume at 20°C and 1 atm. Even when high-quality equipment was used for deairing (Dunnicliff, 1988), some air may remain in the water; therefore, pure water cannot easily be obtained in its natural state. Moreover, the compressibility of pore water increases with the increase in the amount of dissolved air (Richard et al., 1970; Hsu and Chang, 1993). An increase in the compressibility of pore water substantially influences the distribution of consolidation ratios (Hsu and Chang, 1993). Thus, R has great influence on the distribution of hydraulic gradients in a specimen undergoing a consolidation test.

Following the aforementioned research on consolidation, values of compressibility of water (in terms of R) and η can be considered for the purpose of formulating a more general analytical solution for the hydraulic gradient distribution of a consolidation test specimen.

Equation Formulation

In 1925, Terzaghi first developed the following 1-D consolidation equation.

$$c_v \cdot \frac{\partial^2 u_e}{\partial z^2} = \frac{\partial u_e}{\partial t} \qquad (1)$$

In Equation 1, c_v is the coefficient of consolidation; u_e is the excess pore water pressure; z is the spatial dimension in the vertical direction; and t is time. Based on Equation 1, Taylor (1948) presented an analytical equation (Equation 2) that yields the distribution of u_e as both the time factor, T, and the depth factor, z/H, increase.

$$u_e = \sum_{m=0}^{\infty} \frac{2u_{e,0}}{M} \left(\sin \frac{M z}{H} \right) e^{-M^2 T} \qquad (2)$$

In Equation 2, $u_{e,\,0}$ is the initial excess pore water pressure; m is an integer that is not less than zero; $M = 0.5\pi(2m+1)$; and H is the maximum drainage depth for a consolidation specimen.

By taking the gradient of the water head with respect to z, Mitchell (1976) obtained an equation (Equation 3) to determine the hydraulic gradient, i, in terms of both T and z/H.

$$i = \frac{\partial}{\partial z}\left(\frac{u_e}{\gamma_w}\right) = \frac{2u_{e,\,0}}{\gamma_w H}\sum_{m=0}^{\infty}\cos\left(\frac{Mz}{H}\right)\cdot e^{-M^2 T} \qquad (3)$$

In Equation 3, γ_w is the unit weight of water. Since i varies with z/H in a specimen during a consolidation test, initially, $u_e = u_{e,\,0}$ when $z = 0$ (at the top). Then, a non-dimensional hydraulic gradient, p, is defined as $i\gamma_w H / u_{e,\,0}$. Hence, Equation 3 yields

$$p = \frac{\gamma_w H}{u_{e,0}}\frac{\partial}{\partial z}\left(\frac{u_e}{\gamma_w}\right) = 2\sum_{m=0}^{\infty}\cos\left(\frac{Mz}{H}\right)\cdot e^{-M^2 T} \qquad (4)$$

Equation 4 identifies the solutions for the distribution of p as T and z/H change, shown in Fig. 3. Notably, such solutions are useful only under conditions when water and soil solids are assumed to be incompressible, and excess pore water pressure is not measured.

In fact, water is compressible in a real specimen. When air is dissolved in pure pore water, the compressibility of the pore water is considerably increased. Accordingly, solutions in the literature may include significant errors when the compressibility of water is high enough. To eliminate such errors, the first author of this paper proposed the following modified 1-D consolidation equation (Hsu and Chang, 1993) by taking into account R.

$$c_v \cdot \frac{\partial^2 u_e}{\partial z^2} = (1-R)\cdot\frac{\partial u_e}{\partial t} \qquad (5)$$

Perloff, Nair, and Smith (1965) also developed an equation (Equation 6) that governs the change in volume of the water at the bottom of a specimen, when excess pore water pressure is to be measured in a consolidation test with one-way drainage.

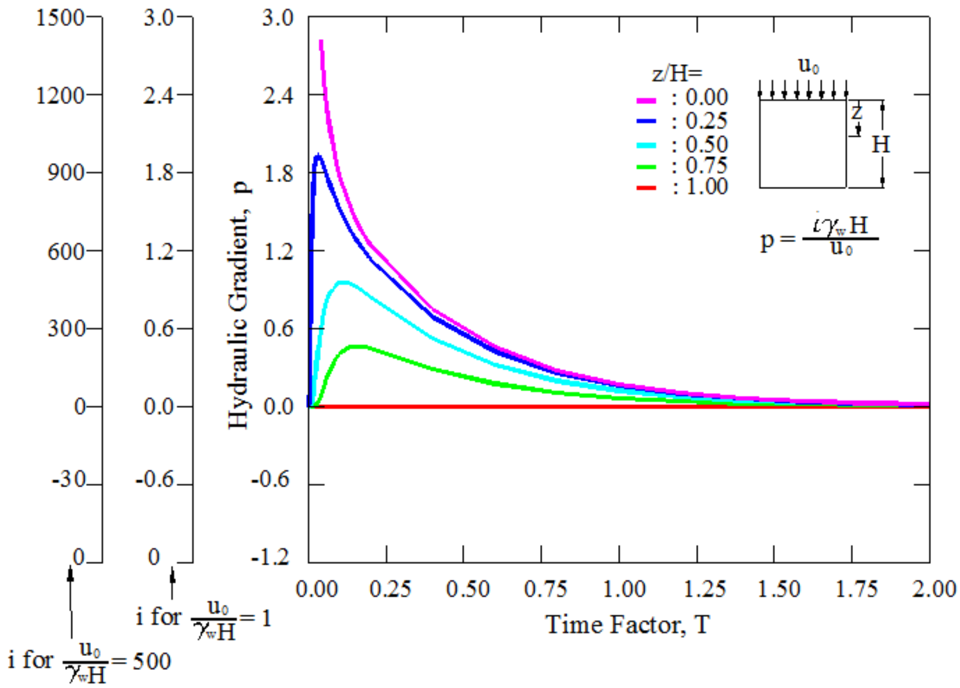


Figure 3. Distribution of p with respect to T for some given values of z/H ($R=0$ and $\eta=\infty$)

In Equation 6, k_z is the coefficient of permeability in the z direction; A represents the cross-sectional area of the specimen; and λ is the change in volume due to the unit change in excess pore water pressure in a measurement system.

Finally, Perloff, Nair, and Smith (1965) determined a solution for u_e (Equation 7) as a function of T, z/H, and η, obtained by solving Eqs. 1 and 6 simultaneously, when the excess pore water pressure is measured. Importantly, these authors assumed that both water and soil solids are incompressible.

$$u_e = 2u_{e,0}\sum_{m=0}^{\infty}\frac{\left(A_m+\dfrac{\eta^2}{A_m}\right)\sin A_m-\eta}{\left(A_m^2+\eta^2+\eta\right)\sin A_m}\cdot\sin\left(\frac{A_m z}{H}\right)\cdot e^{-A_m^2 T} \qquad (7)$$

In Equation 7, η is defined as equal to AHm_v / λ; m_v is the coefficient of volumetric compressibility; and A_m is equal to $(2m+1)\tan^{-1}\eta$.

The above work is extended to conditions under which water is treated as compressible while the excess pore water pressure is measured. The solutions for u_e as a function of the modified time factor T^*, z/H, and η are determined by solving Eqs. 5 and 6 simultaneously.

$$u_e = 2u_0 \sum_{m=0}^{\infty} \frac{\left(A_m + \frac{\eta^2}{A_m}\right)\sin A_m - \eta}{\left(A_m^2 + \eta^2 + \eta\right)\sin A_m} \cdot \sin\left(\frac{A_m z}{H}\right) \cdot e^{-A_m^2 T^*} \qquad (8)$$

In Equation 8, T^* is defined as $c_v^* t / H^2$ and c_v^* is the modified coefficient of consolidation, which equals $c_v / (1-R)$.

After u_e is transferred into the water head, h_w, the hydraulic gradient, i, can be obtained as follows:

$$i = -\frac{\partial h_w}{\partial z} = \frac{\partial}{\partial z}\left(\frac{u_e}{\gamma_w}\right) = \frac{2u_0}{\gamma_w}\frac{A_m}{H}\sum_{m=0}^{\infty} \frac{\left[A_m + \frac{\eta^2}{A_m}\right]\sin A_m - \eta}{\left(A_m^2 + \eta^2 + \eta\right)\sin A_m} \cos\left(\frac{A_m z}{H}\right) \cdot e^{-A_m^2 T^*} \qquad (9)$$

Then, based on Equation 9, a non-dimensional hydraulic gradient, p, similar to the one given in Equation 4 can be obtained as follows:

$$p = 2A_m \sum_{m=0}^{\infty} \frac{\left[A_m + \frac{\eta^2}{A_m}\right]\sin A_m - \eta}{\left(A_m^2 + \eta^2 + \eta\right)\sin A_m} \cos\left(\frac{A_m z}{H}\right) \cdot e^{-A_m^2 T^*} \qquad (10)$$

Numerical Solutions and Discussion

Physical meaning of p

For a consolidation test draining only at the top of the specimen, Fig. 4 depicts the relationships among U_z, T, and z/H for $R=0$ and $\eta=\infty$. Figure 4 shows that when T is a constant, the slope of U_z against z/H is $\Delta U_z/\Delta(z/H)$. When $\Delta(z/H)$ approaches zero, $\Delta U_z/\Delta(z/H)$ becomes $dU_z/d(z/H)$, where

$$U_z = \frac{u_{e,0} - u_e}{u_{e,0}} = 1 - \frac{u_e}{u_{e,0}} \qquad (11)$$

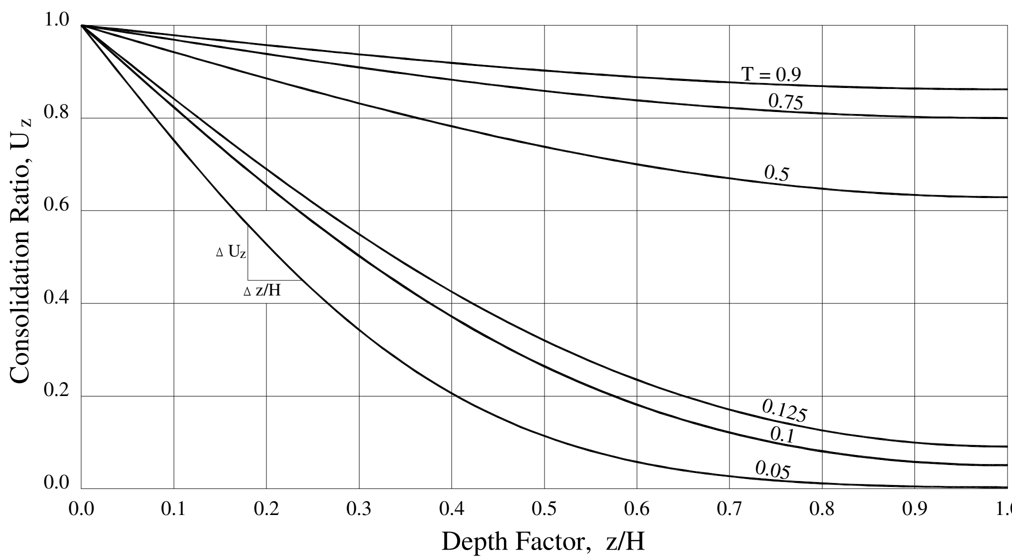


Figure 4. Slope for the curves of U_z against z/H with different values of T when drainage happened only at the top of a specimen ($R=0$ and $\eta=\infty$)

$$\frac{-dU_z}{d(z/H)} = \frac{-d}{d(z/H)}\left(1 - \frac{u_e}{u_{e,0}}\right) = \frac{\frac{du_e}{u_{e,0}}}{\frac{1}{H}dz} = \frac{H}{u_{e,0}}\frac{du_e}{dz} = \frac{H}{u_{e,0}} i\gamma_w = p \qquad (12)$$

Let S_z be the rate of change in U_z with an increase in z/H, such that

$$S_z = -dU_z/d(z/H) = p \qquad (13)$$

Equation 13 shows that p is the negative slope of U_z against z/H. Figure 4 plots the distribution of U_z against z/H, while Fig. 5 shows the distribution of p against z/H for different values of T. The tendency for the variations of U_z against z/H shows that the rate of change of U_z at the top (the drained end) greatly exceeds that at the bottom (the undrained end). Since U_z is the ratio between the dissipated excess pore water pressure and the initial pore water pressure, U_z can be deduced to decrease as z/H increases. Therefore, p also decreases as z/H increases (Fig. 5). For a given value of z/H, u_e decreases as T increases. Notably, the rate of change of U_z, with an increase in T, also tends to decrease. In other words, p tends to decrease as T increases. The ratio z/H is kept constant as p changes with an increase in T, as plotted in Fig. 5. Figure 5 shows that (1) for z/H =0, p monotonically decreases as T increases; (2) for z/H > 0 and T < 0.16, p initially increases and then decreases, as T increases; and (3) the range over which p increases, with an increment in T, tends to increase with increasing z/H.

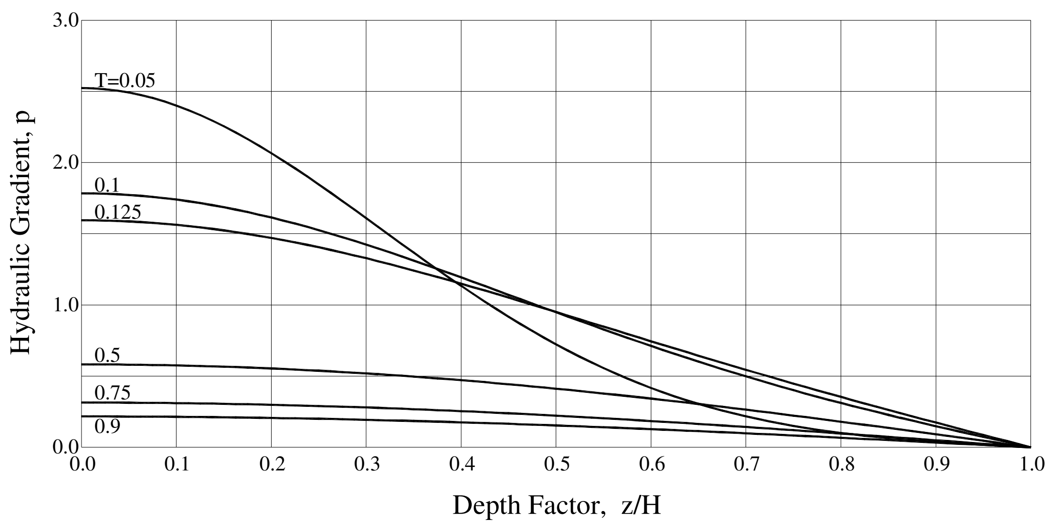


Figure 5. Influence of T on the distribution of p against z/H when drainage happened only at the top of a specimen ($R=0$ and $\eta=\infty$)

Influence of η on the Distributions of U_z and p

In this section, $R = 0$ is applied for all cases. The purpose of choosing $R = 0$ is that some of the solutions can be compared with those obtained by Taylor (1948), Perloff, Nair, and Smith (1965), and Mitchell (1976).

In a consolidation test that involves measuring pore water pressure at the bottom, the variation in p with T and z/H indicate the following results. (1) For $\eta = 10$, a little local drainage is required to enable the measurement system to respond accurately. Figures. 6 and 7 indicate that the change in the bottom boundary conditions forces both the U_z and p curves to become wavy when $T \le 0.01$. (2) When $T \ge 0.1$ and z/H is kept constant, both U_z and its rate of change decrease as η increases with p (Fig. 8). The rate of change decreases rapidly as η increases (Fig. 9). (3) When $T \ge 0.5$, the effect of η on U_z or p is unclear when $\eta > 100$ (Figs. 8 and 9).

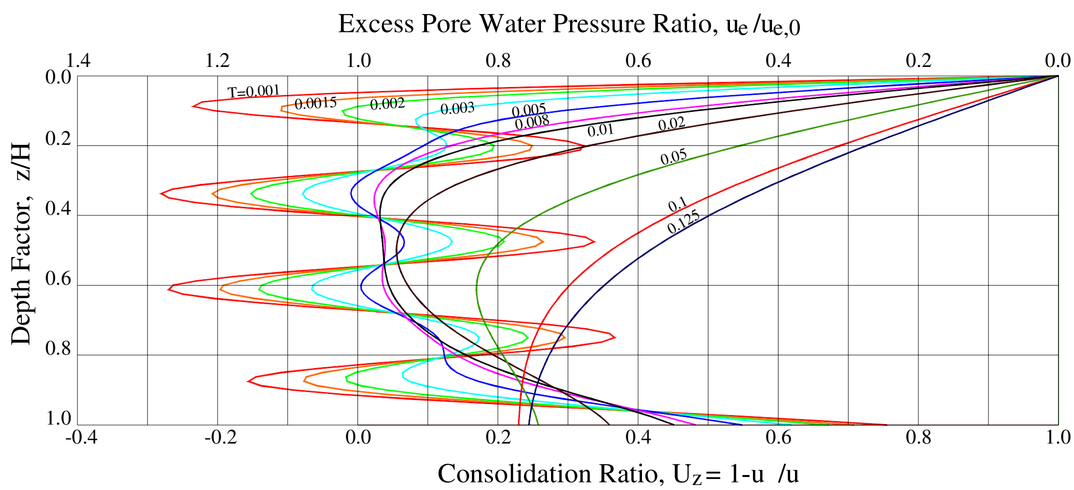


Figure 6. Influence of T on the distributions of z/H against U_z ($R = 0$ and $\eta = 10$)

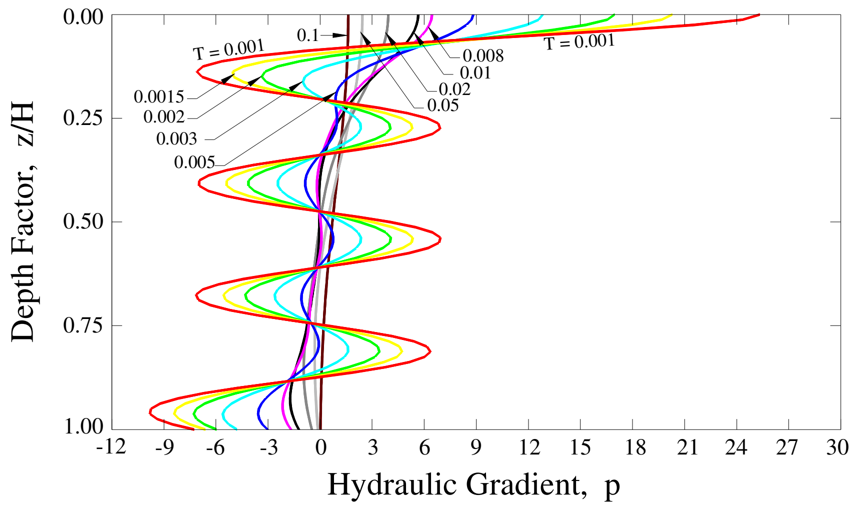


Figure 7. Influence of T on the distributions of z/H against p ($R = 0$ and $\eta = 10$)

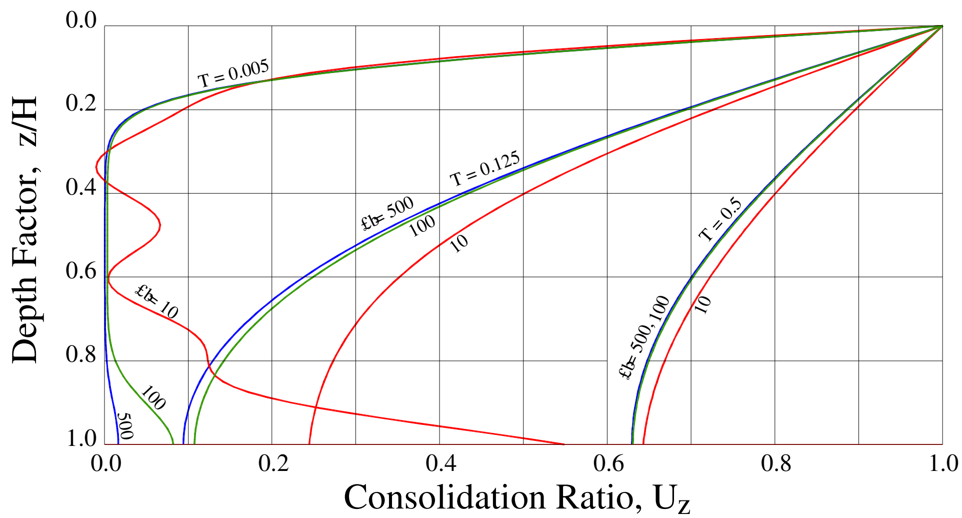
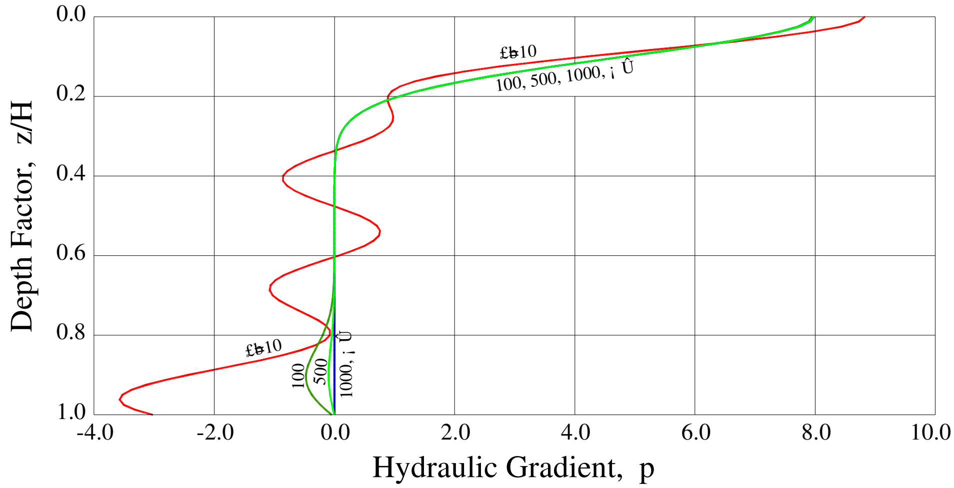
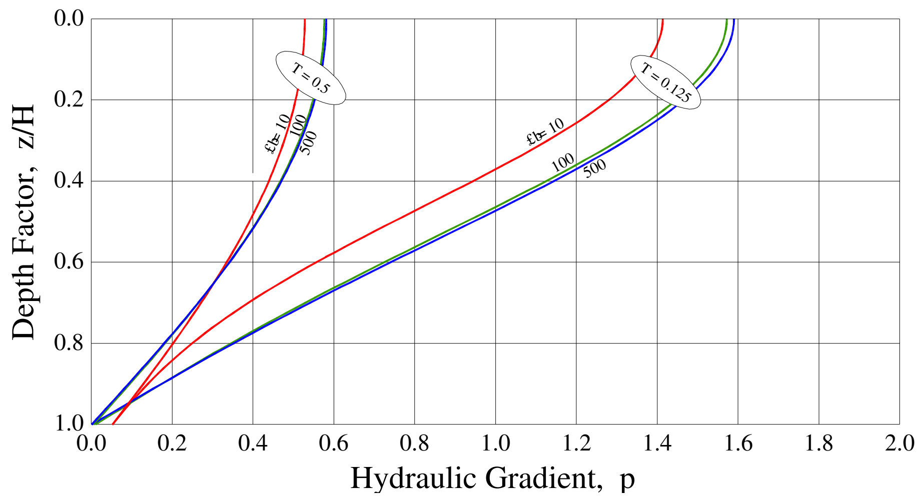


Figure 8. Influence of T and η on the distributions of z/H against U_z ($R = 0$)



(a) $T = 0.005$



(b) $T = 0.125$ and $T = 0.5$

Figure 9. Influence of η on the distributions of z/H against p ($R = 0$)

Clearly, η only affects U_z or p when $z/H > 0.5$ and $T < 0.1$. Therefore, the lower halves of the curves of U_z and p against T are much more complex than the upper halves. Figures 10 and 11 indicate the following: (1) When $\eta \leq 500$, U_z increases rapidly with z/H such that p is more negative at the bottom. (2) As η is further increased, the difference between the two values of p at the bottom becomes insignificant. (3) Since more water must drain from the bottom to allow the measurement system to respond at a smaller value of η, the U_z versus T curve tends to decrease to a minimum and then increase to a specific value. (4) When $T < 0.06$, U_z tends to increase as η decreases. (5) When $\eta < \infty$, U_z initially increases and then decreases, as T increases; this phenomenon differs from when $\eta = \infty$, where U_z decreases monotonically as T increases. (6) When $T > 0.7$, more water must be drained from the measurement system for a smaller value of η before the measured excess pore water pressure is reduced. Then, the nearly consolidated soil at the bottom cannot easily accept back-flowing water, so the resulting value of U_z is smaller (Fig. 11). (7) Referring to the 3D diagram of p, η, and z/H in Fig. 12, some errors occur when η is sufficiently small. Thus, $\eta > 1000$ must be applied as a rule of thumb when choosing an excess pore water pressure measurement system.

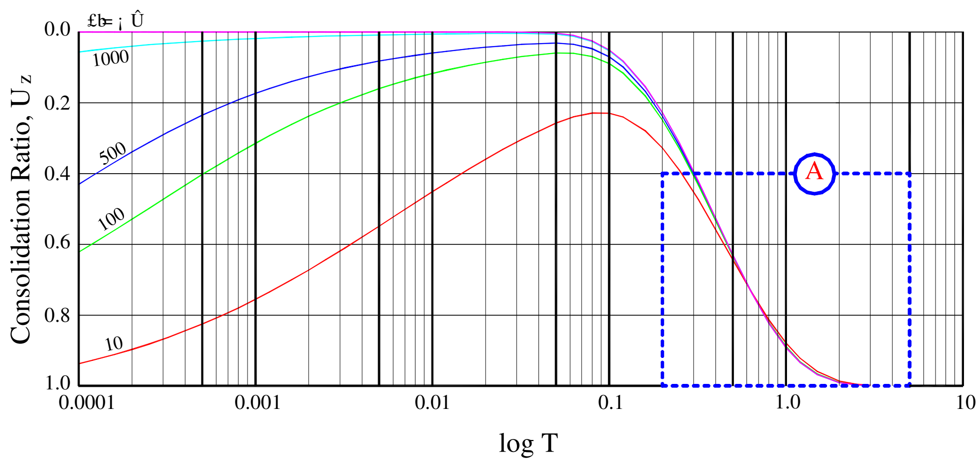


Figure 10. Influence of η on the curves of U_Z against $\log T$ at the bottom of a specimen ($R = 0$)

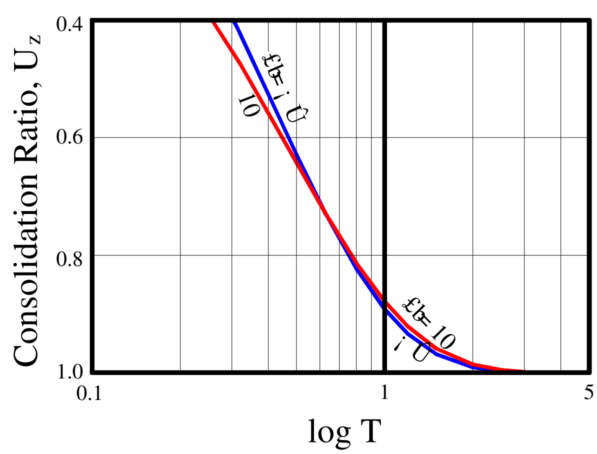


Figure 11. The enlarged part of section A shown in Figure 10

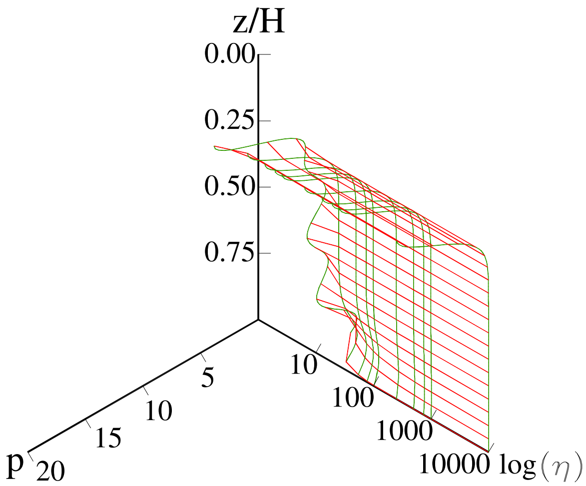


Figure 12. 3-D diagram of p, z/H, and $\log(\eta)$ ($R=0$ and $T=0.005$)

Finally, the solutions in Figs. 3 to 12 are the same as those in the literature when R in Equation 8 or Equation 10 is reduced to zero, establishing the reliability of the solutions in this work. Hence, the following section addresses the variation of R.

Influence of R on the Distributions of U_z and p

For soil containing only pure water and soil solids, R is negligible because c_w is sufficiently small compared to a_v. However, pore water always contains some dissolved air. Under such conditions, c_w increases rapidly and approaches a_v, such that, generally, $0<R<1$. To study the influence of R on the distributions of U_z and p, curves of U_z against z/H and p against z/H are plotted in Figs. 13 and 14, respectively. A 3D diagram of p, R, and z/H is displayed in Fig. 15. These figures show the following. (1) For a given T, the resulting U_z is smaller for $R=0$ than for $0<R<1$, so p at the top ($z/H=0$) increases. (2) When $\eta=100$ and $T=0.005$, the errors in p at the top, due to the assumption that $R=0$, are found to be 100% for $R=0.75$ and 41% for $R=0.5$. (3) When $\eta=100$ and $T=0.125$, the errors in p at the top, due to the assumption that $R=0$, are found to be 171% for $R=0.75$ and 47% for $R=0.5$. (4) When $\eta=100$ and $T=0.5$, the errors in p at the top, due to the assumption that $R=0$, are found to be 3746% for $R=0.75$ and 237% for $R=0.5$. (5) When $\eta=100$ and $T=0.005$, the errors in p at the bottom, due to the assumption that $R=0$, are equal to 733% for $R=0.75$ and 178% for $R=0.5$. (6) Clearly, assuming that $R=0$, as in the Terzaghi one-dimensional consolidation equation, yields considerable percentage errors in p at both ends, especially at low T.

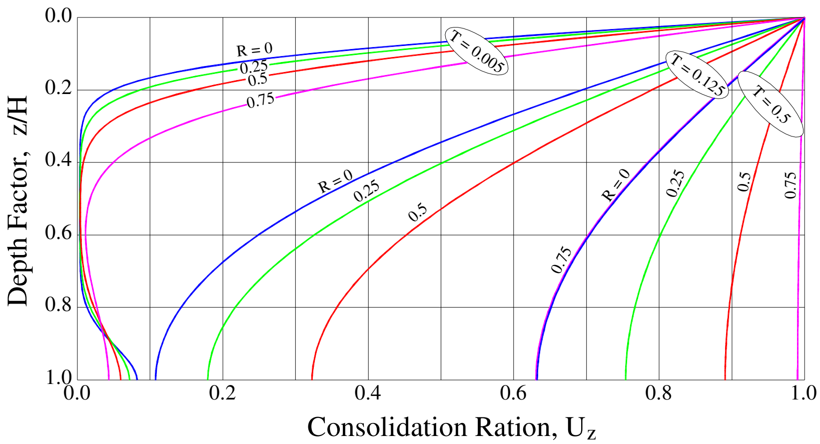
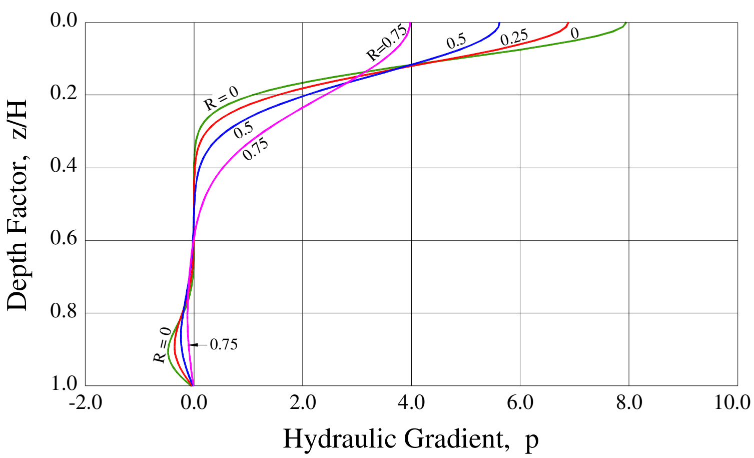
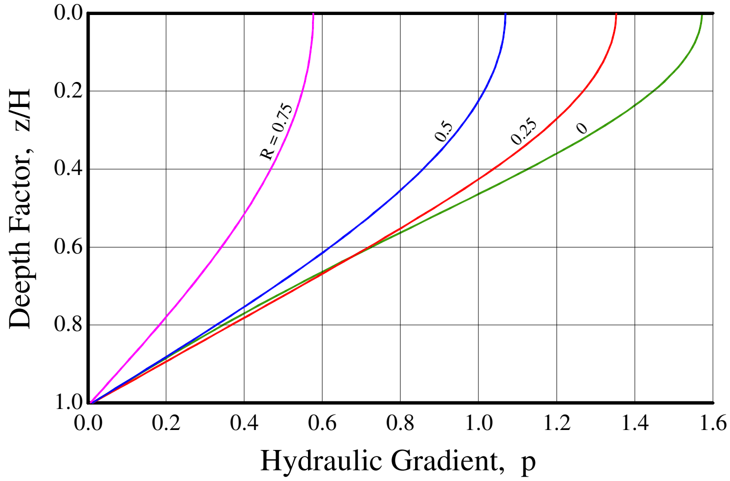


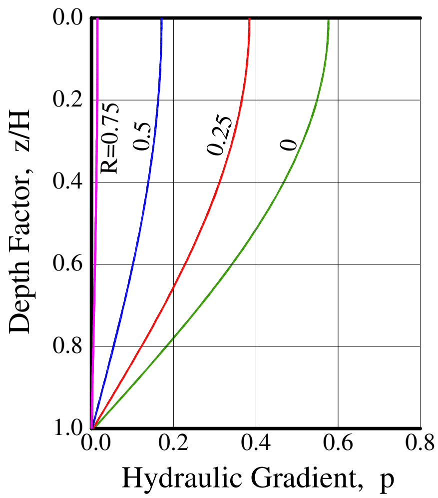
Figure 13. Influence of R on the curves of z/H against U_z ($\eta = 100$)



(a) $T = 0.005$



(b) $T = 0.125$



(c) $T = 0.5$

Figure 14. Influence of R on the curves of z / H against p ($\eta = 100$)

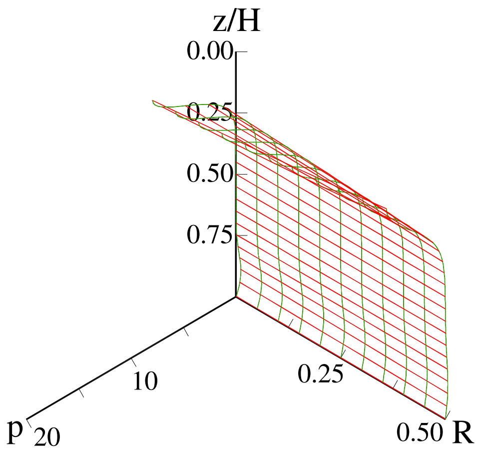


Figure 15. 3-D diagram of p, z/H, and R ($\eta = 100$ and $T = 0.005$)

Influence of T on the Distributions of U_z and p

For a consolidation test under a specific load, U_z normally increases as T increases for the entire specimen. Figure 16 plots the change of U_z with T and z/H when $R = 0$ and $\eta = 100$ (or $\eta = \infty$). The figure reveals the following. (1) When $T < 0.05$, U_z increases initially and then decreases, as z/H increases. (2) When $T \geq 0.05$, U_z decreases monotonically as z/H increases. (3) When $\eta = \infty$, U_z at the bottom decreases monotonically as T increases. However, such values of U_z will be unstable when $\eta \leq 100$ and $T < 0.05$. (4) Only when $T \geq 0.05$ are the values of U_z at the bottom stable. However, these values are all lower than those obtained when $\eta = \infty$, and the difference between them decreases as T increases.

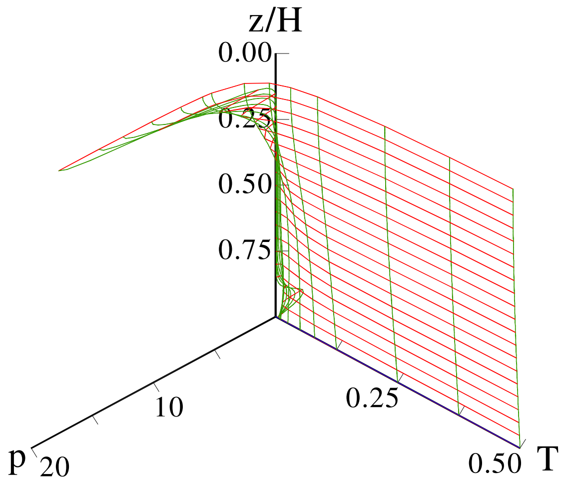


Figure 16. 3-D diagram of p, z/H, and T ($R = 0$ and $\eta = 100$)

For $R = 0$ and $\eta = 100$ (or $\eta = \infty$), a 3-D diagram of p, T, and z/H is plotted in Fig. 16. Projections of p against z/H for various values of T, shown in Fig. 17, demonstrate the following. (1) When $T \geq 0.2$, p decreases to zero as z/H increases, such that all the related curves in Fig. 16 are concave to the left. (2) When $\eta = 100$ and $T \leq 0.05$, as z/H increases, p initially decreases to zero and then falls further to below zero, becoming unstable. Such unstable conditions become worse as T decreases.

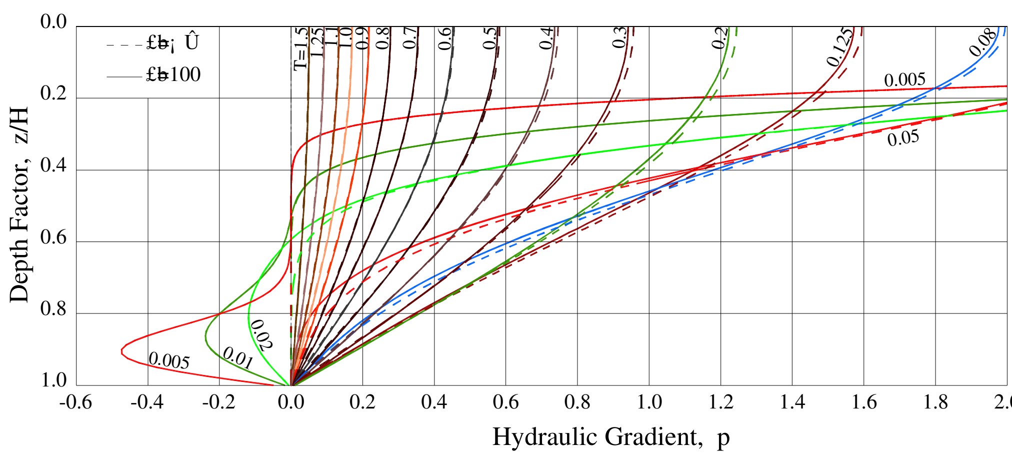


Figure 17. Influence of T and η on the distributions of z/H against p ($R = 0$)

Conclusions

This study presents improved solutions for the hydraulic gradient distribution of a specimen undergoing a consolidation test, especially under the general conditions of $0 \le R < 1$ and $\eta \le \infty$. Based on a thorough description of the physical interpretation of p, solutions for various values of R, η, T, and z/H are obtained.

The results of this study support the following four conclusions.

1. Pore water always includes some dissolved air, so R usually exceeds zero.
2. The consolidation equations based on the assumption that $R=0$ may induce errors. Such errors become significant when more air is dissolved in the pore water.
3. Since the condition that $0 \le R < 1$ is embedded in the modified consolidation equation, the authors' solutions more precisely describe the real consolidation behavior.
4. The value of η strongly affects the resulting hydraulic gradient. Hence, the results of this work reveal that $\eta > 1000$ should be applied as a rule of thumb to select appropriate excess pore water pressure measurement systems.

Acknowledgements

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STAY THERE OR GO AWAY? THE REVISED ADVOCACY COALITION FRAMEWORK AND POLICY CHANGE ON THE PETROCHEMICAL PROJECTS IN TAIWAN

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Abstract

This study concerns about what factors accounting for the petrochemical policy change either of "stay there" or "go away" in Taiwan? And I argue that the Sixth Naphtha Cracking Project's "stay there" in Mailiao in 1991 and the Kuokuang Petrochemical Project's "go away" from Dacheng in 2011 are two good examples for a comparative study. In the regard of the theoretical framework, the revised advocacy coalition framework (ACF) considering roles both of groups of formal and informal actors and *political context* (political power and unique structure of policy subsystem) is decent in explaining Taiwan's petrochemical policy change. On the one hand, groups or coalitions organized by advocates of pro-economic development and pro-environmental protection get involved actively in substantive policy issues. On the other hand, policies are eventually shaped by their confrontation for political power and unique structure of policy subsystem, in terms of democratization. However, as Taiwan fulfilled its democratization and got into democratic consolidation, *citizen*, *citizenship* and *civil society* play an more important role in policy process since they compete with and compel government to transform policy and innovate governance. The study finds that (1) variations of environmental advocacy coalitions are highly affected by change of political regime (from democratizing to democratized); (2) political power is more dependent on the rise of the pro-environmental advocacies, because of political openness and popular awareness generated by democratization; and (3) scholarship shifts to focus on *citizens* and *citizenship* of the society and this is strongly related to Taiwan's 20-year democratic transition.

Keywords: The Sixth Naphtha Cracking Project; The Kuokuang Petrochemical Project; Policy Process and Change; Advocacy Coalition Framework (ACF); Democratization

Introduction

Similar to nuclear power, petrochemical industries are regarded as critical energy resources to facilitate economic growth in Taiwan. Additionally, establishment and expansion of both nuclear power and petrochemical plants lead to a great controversy between advocacies of economic development and environmental protection on the island. Because of the distance between two sides, policy regarding their plant constructions of "to stay there" or "to go away" is heavily influenced by competitions between pro- developmentals proponents and pro-environmentals activists. And the final result, in general, is a consequence of political struggle between these two forces competing for their beliefs, values, and interests.

The Sixth Naphtha Cracking Project conducted by the Formosa Petrochemical Corporation (FPC) and the Kuokuang Petrochemical Project proposed by the Kuokuang Petrochemical Technology Corporation (KPTC), a subsidiary of the Chinese Petroleum Corporation (CPC), Taiwan, are two typical cases demonstrating how environmental movement advocates fight with its counterparts of supporting economic and industrial developments, although the decision-making processes and outcomes vary from case to case. In the case of the Sixth Naphtha Cracking Project, in order to overcome shortage of basic petrochemical materials in Taiwan, the Formosa Plastics Group (FPG) proposed the Sixth Naphtha Cracking Project for alleviating the problem and acquired government's approval in 1986. The first selection for the project site was a 280-hectare property in Lizi, Yilan. But due to serious objections of local people, the project was moved to Guanyin, Taoyuan in 1988, and then aborted for similar reasons. In 1991, the project was chosen to settle down in the off-shore industrial zones in Mailiao, Yunlin, with blessings of both the local government and residents (FPCC, 2012).

Although the Sixth Naphtha Cracking Project is the largest investment of private petroleum and petrochemical industry in Taiwan and it has a great contribution on country's economic development, Bing-heng Chen and Chang-chuan Chan argue that the plant generated huge damages on the local, including change of coastal geomorphology, public hazards and pollution, diminishing of fishery, increase of traffic accidents, irregular trading of housing estate and increase of criminal and sexual industry (Chan, 2005; Chan, 2011). Chan continues to argue that the plant generated air pollution severely nearby the area and provoked pulmonary diseases to residents of Yunlin (Chan, 2015). On July 30, 2010, the FPG was asked by the Executive Yuan (Taiwan's Cabinet) to suspend operation at its fire-hit plant in Mailiao, Yunlin, following protests by local people against the petrochemical plant's poor records of safety and environmental pollutions. The decision appears to result from successful local protests led by Yunlin Magistrate Su Chifen on the one hand and the Central Government's change in attitude empowering the Yunlin County Government on the other hand (The China Post, 2010; Taipei Times, 2010).

In contrast, in the case of the Kuokuang Petrochemical Project, sine the nation would encounter shortage of ethylene by 2015, the government had previously announced its support for the Kuokuang Petrochemical Project. The project was initiated by the state-owned refinery CPC, Taiwan to relocate its crude refining plants in Kaohsiung City to Changhua County by 2015, where the corporation planned to invest NT$400 billion (US$12.57 billion) to construct the petrochemical complex. Planned for construction on reclaimed land off the mouth of the Zhoushui River in western Changhua County, the 2,773-hectare complex is set to be the second largest on the island after FPC's Mailiao refinery complex. Just prior to its relocation to Changhua, the Project was also planned to be built in Mailiao, Yunlin. Based on the result of environmental impact assessment (EIA), however, the KPTC instead proposed to conduct the project in Dacheng, Changhua in 2008 (Taipei Times, 2011a). The project was eventually scrapped by President Ma Ying-jeou's declaration of halting the petrochemical construction on April 22, 2011 and then Premier Wu Den-yih said that the KPTC might seek an alternative location overseas for the project (Taipei Times, 2011b). In sum, scrapping of the Kuokuang Petrochemical Project is regarded as a great triumph for grassroots forces, environmental advocacies, and social movements because pro- environmental groups' actions both heightened public awareness of the issue and stimulated greater public discussion and social mobilization against the construction (Wu and Wu, 2011; Wu, 2012: 143-144).

In the historical context above, a number of concerns nevertheless arise: (1) As we retrospect these two cases, how can the Sixth Naphtha Cracking Project "stay there" in Mailiao? But how can the Kuokuang Petrochemical Project "go away" from Dacheng? (2) In the case of the Sixth Naphtha Cracking Project, why does the FPCC "go away" from Lizi and Guanyin but "stay there" in Mailiao? (3) In the case of the Kuokuang Petrochemical Project, why does the KPTC "stay there" neither in Mailiao nor Dacheng? (4) With the standpoint of Yunlin, why did the county welcome the Sixth Naphtha Cracking Project to "stay there" in 1991 but ask the Kuokuang Petrochemical Project to "go away" in 2008? These four questions could be summarized as one key research question for this study: what factors account for the petrochemical policy change either of "stay there" or "go away" in Taiwan?

Since groups or coalitions organized by advocates of pro-economic development and pro-environmental protection play an important role in the policy process and change of petrochemical constructions in Taiwan, the advocacy coalition framework (ACF) is a primary and decent theoretical framework for this research agenda as the ACF's unit of analysis concentrates on policy subsystems, in which groups of formal and informal actors are involved actively in substantive policy issues (Ellison, 1998: 12). Yet, based on Shu- hsiang Hsu's suggestion, I argue that the ACF needs to take the *political context factor* seriously, but skip the international influence variable, into considering a comparative study on Taiwan's petrochemical policy changes of contrasting the Sixth Naphtha Cracking Plan and the Kuokuang Petrochemical Project, since shifting political context strongly affects the Taiwanese government's decisions of petrochemical constructions but international influences are much insignificant in these two cases.[1]

[1] In his study of a dramatic policy change of scrapping and resuming the Forth Nuclear Power Plant under the Chen Shui-bian's administration in 2000 and 2001, Hsu argues that the advocacy coalition framework (ACF) needs

The paper develops as follows: first, we review key theoretical arguments of the ACF and then we introduce the revised ACF model focusing on political context with less concern about international influence. Second, brief history of the Sixth Naphtha Cracking Project's "stay there" in Mailiao in 1991 and the Kuokuang Petrochemical Project's "go away" from Dacheng in 2008 is brought in the article. Third, based on the revised ACF model, we concentrate on examining advocacy coalitions in different political contexts to compare two cases of this study. Lastly, we conclude that reconsideration of political context in the ACF model is critical in explaining policy changes in Taiwan's petrochemical industries because the effects of advocacy coalition framework on policy process and change are highly associated with impacts generated by political context in particular.

Theoretical Perspective: The Revised Advocacy Coalition Framework

Paul Sabatier's Advocacy Coalition Framework (ACF) is an important theoretical model for studying policy process and policy change. In general, it is based on ideas that interest groups are organized and mobilized in policy communities within a policy domain (Sabatier, 1988, 1998; Sabatier and Jenkins-Smith, 1993, 1999; Birkland, 2011: 298). Although the theoretical framework has been revised and innovated several times since it was first proposed in 1988, the ACF sheds light on analyzing policy studies (Hsu, 2005: 216; Sabatier and Weible, 2007: 189-220). In this section, I briefly review critical literature of the ACF scholarship, and then I move on to introduce the revised ACF model incorporating and emphasizing significance of political context.

1. The Advocacy Coalition Framework: Original

The Advocacy Coalition Framework is a theoretical model for explaining interactions of groups, or coalitions of groups, which are called advocacy coalitions. It typically consists of two to four coalitions form basing on shared beliefs on policy issues. According to Sabatier's proposition, the ACF model has at least four fundamental premises: (1) that understanding the process of policy change—and the role of policy-oriented learning therein—requires a time perspective of a decade or more; (2) that the most useful way to think about policy change over such a time span is through a focus on policy subsystems, that is, the interaction of actors from different institutions who follow and seek to influence governmental decisions in a policy arena; (3) that those subsystems must include an intergovernmental dimension, that is, they must involve all levels of government (at least for domestic policy); and (4) that public policies (or programs) can be conceptualized in the same manner as belief systems, that is, as sets of value priorities

to take both political context and international influences into considering comparative studies on environmental policies (Hsu, 2005). However, as we examine cases of the Sixth Naphtha Cracking Plant and the Kuokuang Petrochemical Project, this study concerns about the political context factor rather than the international factor because the later shows much less significant impact on these two cases. In the prospect of international influences, our literature review shows that neither the project was affected by the governmental(states) and the nongovernmental (MNCs) abroad, nor the advocacy coalition was supported by the nongovernmental (pro-environmental advocates) overseas. Therefore, the international influence factor is insignificant in these two cases.

and causal assumptions about how to realize them (Sabatier, 1993: 16).[2]

The overview of the original theoretical framework is as follows. First of all, the unit of analysis in the ACF is a *policy subsystem*, in which groups organized by formal and informal actors actively participate in policy arena (Sabatier, 1987; Jenkins-Smith, St. Clair, and Woods, 1991). But Brian Ellison argues that the concept of a policy subsystem goes beyond "sub government" or "iron triangles" because members of the system are more dynamic and less formalistic. Policy actors within subsystems, such as researchers, journalists, and activists, form alliances (advocacy coalitions) around their core beliefs or values, and they consider about what public policy should be and what government should do (Sabatier, 1987: 651-652; Ellison, 1998: 12-13). In other words, an advocacy coalition in general consists of those who share common beliefs, values, and identities with respect for a specific policy issue; different advocacy coalitions most often struggle for getting their beliefs, values, and interests translated into governmental programs or policies (Hsu, 2005: 216). Therefore, policy change is in general shaped by competition among different advocacy coalitions, and policy brokers have a stake to mediate the competition, to bridge the distance, and to resolve the problem (Hsu, 2005: 216; Birkland, 2011: 299).

Secondly, in the ACF, Sabatier argues that policy-making within a policy subsystem is influenced both by *relative stable parameters* and *external (system) events*. The stable parameters include (1) the basic attributes of problem area, (2) the basic distribution of natural resources in the society, (3) the fundamental cultural values and social structure, and (4) the basic legal structure, in terms of constitutional and judicial frameworks (Sabatier and Weible, 2007: 190-191; Birkland, 2011: 298). In contrast, external events of the system are dynamic and they include (1) changes in socioeconomic conditions and technology, (2) changes in public opinion, (3) changes in systemic governing coalitions (partisan coalition or alignment in the legislature or the executive branch), and (4) policy decisions and impacts from other subsystems (Sabatier and Weible, 2007: 190-191; Birkland, 2011: 298). The original ACF model is depicted in the top of Figure 1.

Because of its strong explanatory power for policy process and change, the ACF has been applied commonly to a number of studies of policy implementation, policy change, and policy learning. Based on the ACF, for example, Ellison conducted an analysis of policy changes that occurred during the implementation of the Endangered Species Act (ESA) vis-à-vis planning for the construction of the Bureau of Reclamation's Animas-La Plata water project. The analysis reveals how coalitions protect their core policy belief during technical disputes through the acquiescence of secondary aspects of belief system (Ellison, 1998). In the regard of public policy in Taiwan, the ACF model is also applied widely to studies on policy process and change on the island, such as the cases of Su Hwa Highway (Lu and Chang, 2006), Free Port Policy (Lu, 2007), and imposing local taxes in Taoyuan County (Fang and Liang, 2009), etc.

[2] In contrast to Sabatier's proposal, Hsu argues one more premise for the ACF, that is, the role of technical information in the policy process should be addressed (Hsu, 2005: 216; Lu and Chang, 2006: 136).

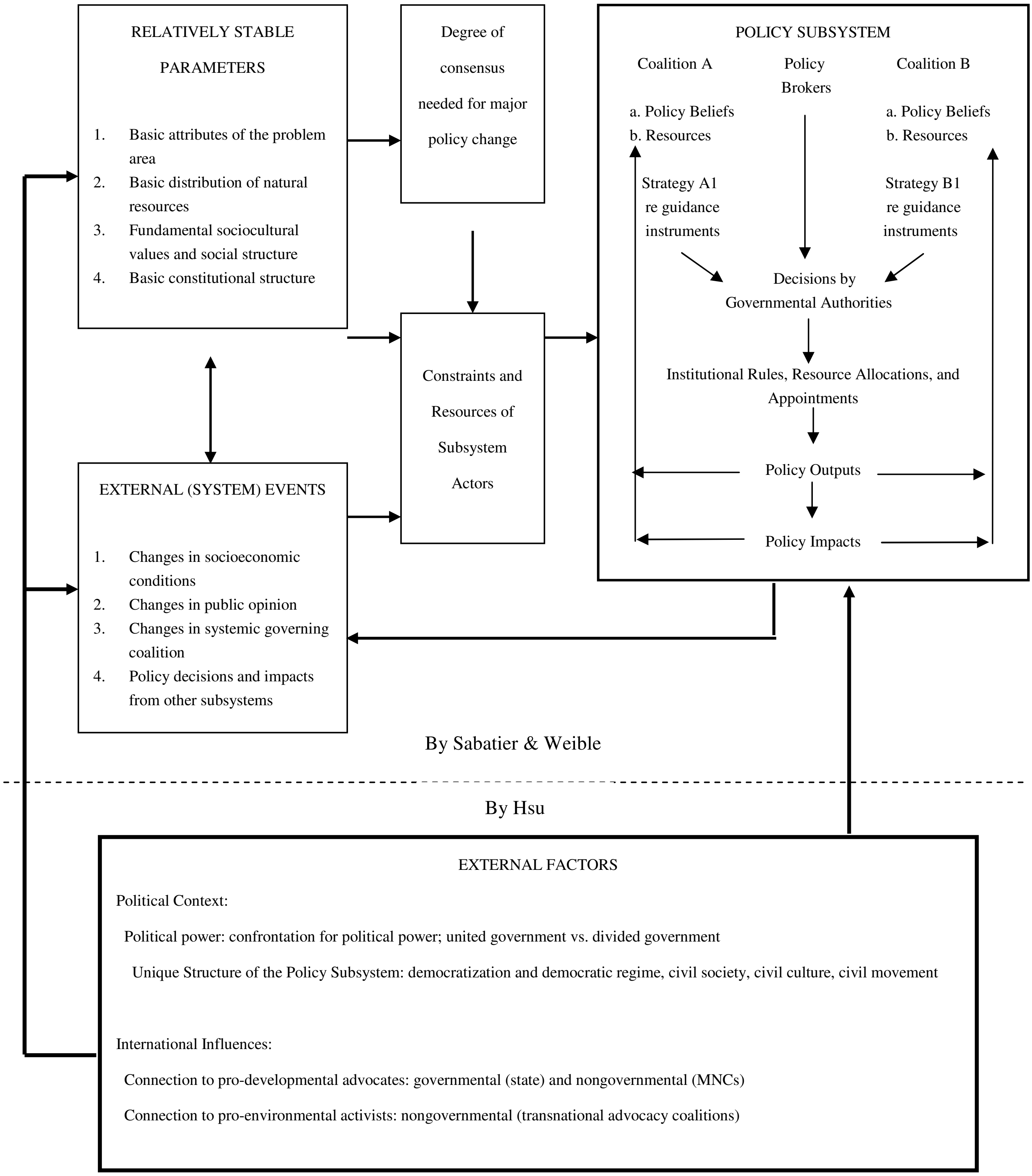

Figure 1. The Revised Advocacy Coalition Framework

Source: Author

2. The Advocacy Coalition Framework: Revised

With the ACF applications and recognitions come criticisms to the model. As Christopher Weible and his colleagues claim, public policy researchers, such as Edella Schlager, Adam Henry, Mark Lubell, and Michael McCoy, have responded to the ACF with increased applications of identifying coalitions by both shared beliefs and coordination patterns (Schlager, 1995; Henry, Lubell, and McCoy, 2010; Weible et al., 2011). Moreover, some other researchers, such as Daniel Kübler, and Christian Hirschi and Thomas Widmer, have applied the ACF in different national contexts and have attempted to develop effective strategies for comparative public policy. They outline some limitations of applicability of the ACF model in different political systems (Kübler, 2001; Hirschi and Widmer, 2010; Weible et al., 2011).

Additionally, based on examining the Chen Shui-bian administration's dramatic policy change of scrapping and resuming the Forth Nuclear Power Plant in 2000 and 2001, Hsu argues that external factors, both political context and international influences, outside policy subsystems are more important than policy beliefs of advocacy coalitions inside the systems in considering comparative policy analysis (Hsu, 2005: 216-217).[3] Here, I concentrate on one of the external factors—political context—to introduce the revised advocacy coalition framework. And it primarily focuses on impacts of political power and unique structure of policy subsystem.

Impact of Political Power

First of all, in the regard of political power, although advocacy coalitions in competition for their impacts on governmental decisions, as the ACF theorists claim, do try hard to translate their policy beliefs, values, and identities into governmental programs and policies, the outcomes of the programs and policies are eventually shaped by their confrontation for political power (Hsu, 2005: 223). In other words, public policy is decided by one who has "upper hands," in terms of political power, over one another.

The logic of political power works as follows: the advocacy coalition actors, to some extent, share not merely common policy beliefs but also reciprocal interests. But, as we move further to distinguish social movement activists from politicians and political parties, their intentions are much different from each other; that is, social movement activists primarily concentrate on a set of core values and beliefs; politicians and political parties, in contrast, emphasize on not merely the advancement of policy beliefs in a particular policy-area but also the ultimate goal of their career or position: stay in political power. Once social movement activists and politicians and political parties could work together on their mutual interests- activists could deliver their votes for politicians and parties, and politicians and parties could put activists' beliefs into practice; they would ally with each other in policy-area against their rivals. Therefore, in the case of the Chen administration's nuclear power policy change in 2000 and 2001, the decision to halt the

[3] In his study, Hsu suggests the ACF model needs to take both political context and international influences into consideration.

Fourth Nuclear Power Plant demonstrates that the Democratic Progressive Party (DPP) government provided a vehicle for anti-nuclear activists and environmentalists to challenge the nuclear project set up by the Kuomintang (KMT) government. In the same way, anti-nuclear activists and environmentalists also delivered their votes and supports for the DPP government's gains in competitions with its opponent, the KMT (Hsu, 2005: 223-224).

In addition to the argument that policy goals and beliefs are often subordinated to the confrontation for political power (Hsu, 2005: 223), here, I further suggest that the DPP government's policy of scrapping and resuming the Forth Nuclear Power Plant also demonstrates another perspective of political power in policy change; that is, *nature* (or *reality*) of political power, which means that who has an "upper hand" over one another. In contemporary democracies, political power is interpreted as who is *majority* in government. It is hypothesized as follows: if the political party can control both over the executive and the legislative branches (the united government model), it is more likely for the party to translate its values, beliefs, and interests into policies of the government. Conversely, if the political party can just control either of the executive or the legislative branches (the divided government model), it is less likely for the party (especially for the one who just controls the executive part only) to translate its ideas and interests into governmental policies, or its policy is most likely to be turn down by the opposition quickly (especially the opposition dominates the legislative part). In the same way, change of the Chen administration's nuclear power policy shows that although the DPP gained control over the administration (the Executive Yuan), it was minority in the Legislative Yuan (Taiwan's Parliament) at that time. The decision to halt the project led to a huge political turbulence that almost threatened to overturn the DPP government, and the KMT's counterattack resulted in administrative stagnation in the government. The revised ACF model regarding political power is depicted in the bottom of Figure 1.

Impact of Unique Structure of Policy Subsystem

Secondly, according to Hsu's argument, another aspect of reconsidering political context is unique structure of policy subsystem; he suggests that the factor of democratization is key both to shape political system and policy subsystem (Hsu, 2005: 224-225). Under authoritarian regimes, in general, the policy-making and decision process are relatively closed to actors outside the government—information is insufficient and incomplete to them and it is difficult for the advocacy coalition activists to mobilize and organize to affect public policy, due to coercion of the authoritarian governments. However, as the political system starts to transit toward a democracy, the "black box" of policy-making process is opened, information becomes transparent and circulating within the political system and policy subsystem, advocacy coalitions of social and environmental movements emerge, and all of these leads to external forces, advocacy coalitions outside the government, on policy process and policy change inside the government. Thus, the revised ACF model focusing on external factors moves further to reconsider the degree of consensus either in transition to democracy or consolidated democracy; the ACF needs to take the political context, in terms of typology of political system, into consideration (Hsu, 2005: 224-225). The revised ACF model regarding unique structure of the policy subsystem is depicted in the bottom of Figure 1.

The unique structure viewpoint is supported by some scholarship comparing advantages of governance of environmental policy between democratic and authoritarian regimes. The literature shows that institutional differences might affect environmental politics and policies. In general, democracies give much greater political roles to ordinary citizens than its authoritarian counterparts do since the political systems are more open to the public, have freer media, and can access to information (Payne, 1995; Neumayer, 2002; Hochstetler, 2012). Additionally, the viewpoint is also supported by some researchers, such as Shui-yan Tang and Ching-ping Tang, and Ming-sho Ho, who examine development of environmental politics and policy in Taiwan primarily focusing on the influence of democratization (Tang and Tang, 1997, 1999, 2000; Ho, 2006). In addition to the emergence of environmental protests in Taiwan's democratizing process (a structural factor), for example, Tang and Tang argue that a retreating authoritarian KMT regime found itself obliged to respect local residents' rights to a clean environment and it chose strategically to make a compromise with pro-environmental advocates (Tang and Tang, 1997). Moreover, not only does the authoritarian government compromise with pro-environmental advocacies initiated by democratic transition, but also bureaucracy under the democratization adjusts to democratic transition on environmental administration and governance (Tang and Tang, 2000). Similar to theory of the advocacy coalition framework, Tang and Tang also argue that pro-environmental advocates not only raise the public awareness of environmental issues, but they also act to influence policy-making by organizing nation-wide demonstrations against governmental policy by privileged groups, lobbying legislators, and campaigning on behalf of candidates for positions in government. The channels, which are created by reconfigurations of institutional arrangements for actors and groups to influence policy making and implementation, are definitely resulted from political openness and liberalization of transition to democracy (Tang and Tang, 1999).

Although the scholarship highlighted impact of democratization in explaining policy process and change in Taiwan, some sociological and environmental-political research moved on to probe the role of *citizen*, *citizenship* or *civil culture* in environmental politics and policy as the KPTC proposed to conduct the Kuokuang Petrochemical Project in 2008. Ho argues that scrapping of the project in April 2011 was not only a triumph for the environmental advocates in Taiwan, but also it was a paradigm for civil actions and movements on the island. There are two essential elements, as Ho claims, in the civil movement of anti- Kuokuang Petrochemical Project: one is that the civil movement is beyond partisan position overall; they are not for any specific political party or faction. The other is that the civil movement is based on altruism; they are not selfish for any specific interest group or political party (Ho, 2012: 47-48). Interestingly, the KMT government eventually took the pro- environment stance with its rival, the DPP, in this case whenever the two forces have clashed over time. Therefore, some enlightenments are shown in the case that perhaps scholarship in policy process and change needs to shift from the democratization focus to the democratic consolidation view to probe unique structure of the policy subsystem in Taiwan, as the island completed its transformation from a transitional democracy to a consolidated democracy, in which the influence of civil society should be more significant than other factors to policy process and change of the government (Ho, 2012: 47). Kuei-tien Chou also argues that a strong civil society across partisan lines is critical to compete with and compel government, in terms of constructing transformative policy and innovative governance (Chou, 2015).

Comparisons of "Stay There" of the Sixth Naphtha Cracking Project and "Go Away" of the Kuokuang Petro-Chemical Project

In this section, I conduct a comparative study regarding policy process and change on the petrochemical projects in Taiwan. And I try to answer the first question raised in the introduction part: how can the Sixth Naphtha Cracking Project "stay there" in Mailiao in 1991? But how can the Kuokuang Petrochemical Project "go away" from Dacheng in 2008? The empirical analysis is based on the revised ACF model emphasizing significance of advocacy coalition framework and political context of two key variables: political power and unique structure of policy subsystem. Moreover, the research is developed following the Most Similar System Design (MSSD, also the method of disagreement) because both the Sixth Naphtha Cracking Project and the Kuokuang Petrochemical Project share a number of similarities, such as project goal for economic development, multi-billion investments, under the pro-economic developmental KMT government, similar party attitudes of the KMT and the DPP, and insignificant international influence. Based on these similarities above, this study concentrates on examining how disagreements between two sides lead to different outcomes of the projects (see Table 1).

1. The Original Advocacy Coalition Framework Perspective

First of all, in the regard of impact of the advocacy coalition framework on Taiwan's petrochemical policies, it is clear to see influence of the ACF in the Sixth Naphtha Cracking Project is weak. Instead, power of the ACF in the Kuokuang Petrochemical Project is strong. This significant difference leads to different fates of the projects.

In the case of the Sixth Naphtha Cracking Project in 1991, the environmental advocacy coalition, primarily Taiwan Environmental Protection Union and its Yunlin branch, was not strong enough to keep the project out of the county. In the process of choosing to settle down in the off-shore Mailiao and Haifong industrial zones, protests against the FPCC did take place. However, these protests were neither nationwide nor powerful in the county. According to Shou-Jung Yang's research findings, most of the protests were from coastland aquaculture in local and their primary concern was compensation, which had to be provided by the FPCC, since the farms of cultivation industry would be gone after construction of the plant (Yang, 1994). On the other hand, as the FPCC successfully convinced the local government and people of the

Table 1. Comparisons between the Sixth Naphtha Cracking Project and the Kuokuang Petrochemical Project

	The Sixth Naphtha Cracking Project (1991)	The Kuokuang Petrochemical Project (2011)
I.V. (1)* Policy Goal	Economic development	Economic re-development
I.V. (2) Investment	Multi-billion (US$17.7 billion)	Multi-billion (US$32.2 billion)
I.V. (3) Administration	The KMT in power	The KMT in power
I.V. (5) Party Attitudes	The KMT: support The DPP: insignificant	The KMT: from support to not support The DPP: from support to not support
I.V. (6) International Influence	Insignificant	Insignificant
I.V. (7) *Advocacy Coalition*	*Environmental advocacy coalition was weak*	*Environmental advocacy coalition was strong*
I.V. (8) *Political Context 1: political power*	*In favor of economic development*	*In favor of environmental protection*
I.V. (9) *Political Context 2: democratization*	*Developing and immature democracy* *Weak civil-social movement*	*Developed and mature democracy* *Strong civil-social movement*
D.V.** *Policy Outcomes*	*Stay there in Mailiao*	*Go away from Dacheng*

* I.V.: independent variable.

** D.V.: dependent variable.

Source: Author

county by providing incentives of economic development and job opportunity to them, the company quickly broke down the potential of forming large-scale demonstration and protest against the petrochemical project. Additionally, the FPCC also politically aligned local factions to run counter to pro- environmental activists (Tang, 1999; Chan, 2005; Huang, 2011). In doing so, the Sixth Naphtha Cracking Project was successfully put into practice in Yunlin. In retrospect of history of construction of the Sixth Naphtha Cracking Project, I argue that the weak advocacy coalition against the project at that time was highly associated with then political context, in terms of the bottom-up voices from civil society of the island, because Taiwan just began to liberalize and democratize (Taiwan started with its liberalization and democratization in the end of the 1980s). Although the power of civil society emerged dramatically in the early 1990s, pro-environmental voice and popular awareness of environmental protection, either in the national level (nation) or in the sub- national level (city or county), were not strong enough to overcome governmental and non-governmental support of the petrochemical project construction in favor of Taiwan's economic development. Additionally, a relatively weak influence of environmental impact assessment (EIA) was another key in the case. Although potential damages of public health and ecosystem were emphasized in the EIA of the Sixth Naphtha Cracking Project, the FPCC promised to decrease the risks at the beginning of the plant (Tu and Shih, 2014: 99). This did weaken power of the advocacy coalition against the project. Therefore, a relative weak and immature advocacy coalition framework in the Sixth Naphtha Cracking Project, compared to its Kuokuang Petrochemical Project counterpart, was key that the FPCC could stay in Mailiao, Yunlin.

Conversely, in the case of the Kuokuang Petrochemical Project in 2011, impact of the ACF in the project was much more powerful than that of advocates' connection and coalition against the Sixth Naphtha Cracking Project in 1991. Just prior to its plan to construct the factory in 2008, the KPTC's proposal just underwent a lot of criticisms and challenges, especially from environmental impact assessments (EIAs) in profession and Taiwan's civil society. Since 2010, the island has undergone a number of demonstrations and protests to call for the government to halt the Kuokuang Petrochemical Industry Plan. In the whole process from proposal of the plan to President Ma's decision to cease the construction, the anti- Kuokuang Petrochemical Project movement almost became a perfect model of Taiwan's resurging civil-social movement focusing on environmental protection. The campaign inspired lots of people with different backgrounds, including professors and scholars, white collar workers, peasants, labors, students, and writers and artists, to concern about not only environments, but also protection of great nature and disparity between rural and urban areas. It also generated awareness of local identity for people on the island (Wu, 2012). Overall, scrapping of the Kuokuang Petrochemical Project is also regarded as a triumph for all of grassroots forces, environmental advocacies, and social movements because pro-environmental groups' actions both heightened public awareness of the issue and stimulated great public discussion and social mobilization against the construction (Wu and Wu, 2011; Wu, 2012: 143-144).

Clearly, the advocacy coalition in this case, across different groups and areas, did play an important role in impacting the government's policy. A number of literature also demonstrates that the advocacy coalition in opposition to the project is a new *paradigm* to social and environmental movements in Taiwan due to its multivariate advocates from different fields, informational openness, comprehensive civil participation, abundant social discourses, and professional environmental impact assessment, etc (Taiwan Environmental Protection Union, 2012; National Youth Alliance Against Kuokuang Petrochemical Project, 2012).

Similarly, in retrospect of progress of the Kuokuang Petrochemical Project, some conditions in the policy process and change vary from those in the Sixth Naphtha Cracking Project. As I look at significant influence of the powerful and successful advocacy coalition in this case, the strong advocacy coalition running counter to the plan at this time was highly related to contemporary political context, which implies the bottom-up voices from civil society in Taiwan. Explicitly, after 20-year democratization, Taiwan already transforms to be a consolidated democracy. Although a number of problems take place in the democracy, in the regard of environmental issues, civil voices of protecting environment and the environmental advocacy coalition turns much greater than those in transition to democracy. Therefore, compared to its counterpart against the Sixth Naphtha Cracking Project, a relatively stronger advocacy coalition is critical to convince the KMT government and President Ma's decision to halt the Kuokuang Petrochemical Project. And a much more powerful advocacy coalition is shaped by political context of the completed democratization, as well as a relatively mature and strong civil society, in Taiwan.

2. The Revised Advocacy Coalition Framework Perspective

In this section, I compare the Sixth Naphtha Cracking Project's "stay there" in Mailiao and the Kuokuang Petrochemical Project's "go away" from Dacheng in two dimensions: political power and unique structure of the policy subsystem. Here, I find that although policies of these two projects were made by the united KMT governments (the Lee Teng-hui-led KMT government in the 1990s and the Ma Ying-jeou-led KMT government in the 2010s), two central governments under two KMT leaders in favor of different positions lead to different policy outcomes—the one (the KMT government under Lee) supporting *economic development* results in the Sixth Naphtha Cracking Project's "stay there" and the other (the KMT government under Ma) compromising with *environmental protection* lead to the Kuokuang Petrochemical Project's "go away." Still, this scenario reflects reality of political power, which implies that governmental policy is decided by one who has an advantage in political power. But, in the comparison, political power here is a struggle between government and society (and advocacy coalition) instead of competitions between political parties in the nation. Additionally, different petrochemical policy outcomes are significantly affected by various and specific unique structures of the policy subsystem. The Sixth Naphtha Cracking Project is less impacted by democratic transition in Taiwan, as I discuss in the previous section. But the Kuokuang Petrochemical Project is explicitly influenced and driven out by the civil movement against the plan, which is under relatively mature civil culture stemming from Taiwan's fulfillment of democratization and its consolidated democracy.

Political Power in Favor of Economic Development or Environmental Protection

First of all, from the perspective of political context, in the case of the Sixth Naphtha Cracking Project, regardless of national or sub-national politics, the then pro-environmental opposition (the DPP) was not strong enough to withstand the ruling KMT's proposal at that time. On the other hand, the political system and policy subsystem of Taiwan were just in transition to democracy; civil society and civil culture on behalf of environmental protection was still developing at that time. In general, these conditions were not beneficial yet to the pro- environmental activists who opposed the project, although the democratization generated a great advantage for them in a long term (Tang and Tang, 1997; Tang, 1999). Thus, in the regard of political power, the ruling KMT had superiority on the opposition DPP; the ruling KMT government in support of petrochemical industry and economic development for the nation prevailed over the society and advocacy coalition in side of environmental protection for the island.

However, in the case of the Kuokuang Petrochemical Project, interestingly, both the KMT and the DPP changed their attitudes toward the plan from support to not support. Tsai Ing- wen, the DPP presidential candidate in 2012, expressed open opposition to the project, but she was supportive of it when she was vice premier under the Chen Shuibian's administration, 2006-2007 (Taipei Times, 2011c). Similarly, President Ma Ying-jeou, also the KMT presidential candidate in 2012, finally decided to halt the project, but he was supportive of it just prior to the election. Both presidential candidates' attitude changes demonstrate that the Taiwanese government, political elites, and their parties did make a great concession to the pro-environmental advocacy coalition in the case, as they considered popular votes for the campaign to win the election. Additionally, scholars also argue that the anti-Kuokuang petrochemical movement is a typical example of *social practice* inspired by citizens' awareness of environmental protection beyond any specific partisan position and self-interest (Chuang, 2011; Ho, 2012; Tsai, 2012; Wu, 2012). Certainly, this is a great achievement of Taiwan's democracy, which is fulfilled by its democratization over the past twenty years. Therefore, I conclude that political power (two major political parties with pro-environmental advocacy coalitions in Taiwan) in support of environmental protection is key leading to the Kuokuang Petrochemical Project's "go away."

Variations of Unique Structure of Policy Subsystem

Secondly, in the comparison, I argue that different outcomes of petrochemical policy in Taiwan are significantly impacted by different unique structures of the policy subsystem. In other words, a relative developing and immature democracy in transition is insignificant to success of advocacy coalition and social movement against governmental policy in the side of petrochemical enterprises. In contrast, a relative developed and mature democracy in solid is much beneficial to success of activists of advocacy coalition and social movement to prevail over the government-petrochemical enterprise coalition (Grano, 2015).

As I discuss in the previous section, unique structure of the policy subsystem, in terms of democratization, the Sixth Naphtha Cracking Project in the 1990s was opened and generated opportunities for pro-environmental advocates and social movements to run counter to the government's plan in support of economic development. However, the junior democratic system did not really generate a powerful advocacy coalition against the project either nationwide or in local, although the project was rejected in Lizi, Yilan and Guanyin, Taoyuan in the 1980s. Instead, the Kuokuang Petrochemical Project was significantly impacted by a strong advocacy coalition and popular social movement. And indeed, Taiwan's fulfillment of democratization and its relatively mature civil culture and society in the 2010s were much beneficial to success of the movement to overcome the project.

Moreover, while examining some details of developing democratization in the 1990s and developed democratization in the 2010s, I find that the significant distinction of advocacy coalition and social movement between these two cases (a weak ACF in the Sixth Naphtha Cracking Project vs. a strong ACF in the Kuokuang Petrochemical Project) is highly associated with variations of the development of Taiwan's democratization. Compared to the FPCC's Sixth Naphtha Cracking Project, the KPTC's Kuokuang Petrochemical Project encountered a large-scale coalition of opposition from Taiwan's society, including pro-environmental advocates, professors and scholars, white collar workers, peasants, labors, writers and artists, and students (Wu, 2012). During the campaign, they not only criticized the disadvantage of Taiwan's petrochemical industry policy, but also they successfully aligned with each to call for people's awareness of respect and protection of great nature, land ethics, environmental justice, and sustainable development of the society (Tsai, 2012). Indeed, Taiwan's citizens, its citizenship and civil culture play a very critical role in rejecting the construction of the Kuokuang Petrochemical Project. Thus, Ho considers that scrapping of the project in April 2011 is a new paradigm for civil movements in Taiwan (Ho, 2012: 47-48). For academy either in the field of environmental study or public policy, I recommend that perhaps scholarship in policy process and policy change has to rethink of the shifting research focus from democratization to democratic consolidation and civil society in examining how advocates and activists of the anti-Kuokuang petrochemical movement play and perform the role of *citizen and citizenship* on this matter (Ho, 2012: 47). The anti-Kuokuang case not only establishes a good model of developing systemic knowledge against official discourse, but also conveys general perceptual ideas among people and encourages a strong voice from the public (Chou, 2016). Citizens in the case just demonstrate their concerns about a better and cleaner environment, beyond any political positions either of green or blue.

Conclusion

Innovation of the Revised ACF for Policy Process and Policy Change

According to the comparative study on policy process and change between the Sixth Naphtha Cracking Project and the Kuokuang Petrochemical Project, I argue that the ACF model is still advantageous to study petrochemical policy in Taiwan. However, the original framework is insufficient to examine and compare these two cases. I use Hsu's proposition to generate a revised ACF model focusing on two factors of political context—political power and unique structure of the policy subsystem—for analysis. Based on study above, some conclusions are summarized as follows.

First, in this comparison, variations in environmental advocacy coalition, in terms of its shift from weak impact to strong impact on governmental policy, is still essential to explain whether the petrochemical plants "stay there" or "go away" from the place in Taiwan. It is still the key to see if the government sticks on or gets rid of its original attitude toward petrochemical industry on the island. My study also indicates that the variations are highly affected by change of the political regime or institution (democratization from a developing and immature democracy to a developed and mature democracy), and this does echo previous democratization-oriented scholarship on policy process and policy change.

Second, some other external factors outside the policy subsystem are necessary for reconsidering the comparative study. In the regard of political context, the idea of political power is still an enduring principle in explaining action or choice of any politician, political party, and government. Yet, the idea of political power is more dependent on rise of the pro-environmental advocacies and social movements, because of political openness and popular awareness generated by democratic transition. This tendency demonstrates why both the KMT (Ma Ying-jeou) and the DPP (Tsai Ing-wen) shifted their attitudes toward the Kuokuang Petrochemical Project from "support" to "not support," and decided to halt the project finally.

Third, moreover, in the regard of political power, although ultimate decisions of these two projects were made by the united KMT governments, two central governments under two KMT leaders (Lee Teng-hui in the 1990s and Ma Ying-jeou in the 2010s) in favor of different positions resulted in different policy outcomes. The Lee-led KMT government supporting economic development led to the Sixth Naphtha Cracking Project's "stay there" in Mailiao and the Ma-led KMT government compromising with environmental protection led to the Kuokuang Petrochemical Project's "go away" from Dacheng.

Fourth, in the regard of unique structure of the policy subsystem, previous studies were greatly concentrated on democratization and democratic regime. However, recent scholarship shifts to emphasize the role of *citizens and citizenship* of the society, including ideas of civil society, civil culture, and civil movement, etc. Clearly, as a new paradigm for social movements in Taiwan, this research transformation is dependent on success of the pro- environmental advocacy coalition and rise of popular awareness against the Kuokuang Petrochemical Project in 2011. Indeed, this is strongly related to a developed and mature democratic regime in Taiwan, after its 20-year democratic development.

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AN INNOVATIVE SYSTEM USING ORIGINAL RESIDENTIAL WATER TOWERS AND PIPES TO SUPPLY SOLAR UV-LAMP STERILIZED TAP WATER TO HOUSEHOLDS

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Abstract

In Taiwan, the production of in-house electric energy and the economization of electric energy are public affairs most worthy of concern and popularization. They are related to the justifiability of the advocacy of carrying on nuclear electric power generation in Taiwan, with deep concern of its frequent earthquakes. Moreover, can Taiwan's annual CO_2 emission reduction meet the requirement of the Kyoto Protocol? In terms of the production of in-house of electric energy in Taiwan, hydraulic energy, wind energy, solar energy, waste energy and biodiesel energy are not yet ideal. Therefore, how to economize power utilization becomes a subject of great concern. The tap water from residential water towers is sterilized by ultraviolet germicidal lamps, which has been proved to produce almost aseptic tap water. A cardiac catheter material-like tubule is inserted into the original water pipe, starting from the original residential water tower and ending in kitchen. The aforesaid aseptic tap water is delivered through the tubule at a low rate and stored in the room as reserved drinking water. This potable water system design has the following features: (1) omitting the original procedure of boiling tap water before drinking to economize power resource; (2) using human cardiac catheter material as the tubule to deliver aseptic tap water, while

the material is very stable at high temperature, there will not be rough inner wall of tubule because rough tube walls are likely to breed bacteria. (3) using jets water backward at the front end of a water pipe, this special equipment generates a counter-force to push the tubule forward in the original water pipe till it reaches the kitchen outlet. (4) if necessary, setting an optical fiber around the aforesaid tubule, the tubule can have the transmission function of a network cable.

Keywords: Carbon Dioxide, Drinkable Tap Water, Ultraviolet Sterilization, Cardiac Catheter Material

Background

In terms of Taiwan's CO_2 emission, its ranking is the power generation industry, rail/road transport and steel, cement, and petrochemical industries (Tsai & Chen, 2001). In Taiwan, electric energy shall be highly considered among all energy sources, which is related to frequently occurring earthquakes and their effect on nuclear electric power generation; and whether Taiwan's annual CO_2 emission rate can attain the goal of CO_2 reduction, as established by the Bureau of Energy, Ministry of Economic Affairs (Chen & Chen, 2012). The aforesaid goal is established by the Bureau of Energy according to Taiwan's industrial CO_2 emissions, as required by the Kyoto Protocol. After the Fukushima nuclear catastrophe, the nuclear power policy of Taiwan was strictly reviewed regarding whether Taiwan shall exercise a nonnuclear homeland policy in the long-term. This paper hopes to implement the energy saving policy of drinkable tap water in Taiwan, where the energy saving effect of this energy saving policy is provided as reference for the government to establish a power utilization policy.

Taiwan is very short in energy, and its energy is mostly supplied from the Middle East and Indonesia, which are far away. Thus, their transport and transaction costs are high. And, the energy supply market is very likely to be monopolistic or oligopolistic. As Taiwan is confronted with such unstable energy supply situation, it highlights the importance of indigenous energy production and energy saving. In terms of indigenous energy production, Taiwan's indigenous energy is mainly renewable energy at present, including hydraulic energy, wind energy, solar energy, waste energy, and biodiesel energy. Taking power generation as an example (referring to Table 1), hydro power generation is limited by decreasing water resources in Taiwan, and there is little opportunity for development. Wind power generation generates low-frequency noise and landscape damage in operation, and thus, is protested by residents. Solar power generation costs are as high as 4 times that of biomass power generation costs (Chen & Chen, 2012). In terms of waste power generation, while garbage classification is quite good at present, many incinerators have no waste to burn. The installed capacity of nuclear electric power generation remains stable in Taiwan, whereas the installed capacity of thermal power generation increases year by year, as shown in Table 2. Coal fired power generation has the largest proportion in the most striking CO_2 emissions, as each kWh of electricity generation produces 900~1000 g CO_2 according to the coal quality, which is

2~3 times that of natural gas (Chen & Chen, 2012). The CO_2 emission resulted from such a high percentage of thermal power generation is adverse to Taiwan's image in the global consensus on greenhouse gas reduction, and thus, may incur international sanctions.

As stated above, how to develop biomass energy and save energy are urgent energy policy issues for Taiwan at present. The drinkable tap water policy is an instantly effective policy for energy saving, which is why this paper aims at a system design that uses original residential water towers and pipes to deliver drinking water sterilized by solar energy electricity storage UV-lamp to households.

Energy Saving with Drinkable Tap Water in Taiwan

Lin (2007) compiled Taiwan's drinking water regulations regarding tap water quality as the objective of tap water quality management. The objective implementation rules included water source protection to maintain clean water, and enhancing the water purification monitoring system, water quality

Table 1. The Renewable Energy Installed Capacity in Taiwan in Recent 10 Years

Year	Total	Conventional Hydro Power	Wind Power	Solar Photo-voltaic	Biomass	Waste
2005	2,607.6	1,909.7	23.9	1.0	99.1	573.8
2006	2,739.4	1,909.7	102.0	1.4	116.8	609.5
2007	2,848.9	1,921.2	186.0	2.4	116.8	622.5
2008	2,933.1	1,937.9	250.4	5.6	116.8	622.5
2009	3,060.0	1,936.9	374.3	9.5	116.8	622.5
2010	3,214.6	1,977.4	475.9	22.0	116.8	622.5
2011	3,417.1	2,040.7	522.7	117.9	111.3	624.4
2012	3,615.4	2,081.4	571.0	222.5	111.3	629.1
2013	3,828.1	2,081.4	614.2	392.0	111.3	629.1
2014	4,079.2	2,081.4	637.2	620.1	111.3	629.1
2015	4,318.6	2,089.4	646.7	842.0	111.3	629.1

Unit: MW
Source: Bureau of Energy (2016)

Table 2. The Capacity of Power Generating in Taiwan in Recent 10 Years

Year	Grand Total	Pumped Hydro Power	Coal-Fired	Oil- Fired	LNG Fired	Nuclear Power

2005	43,162.6	2,602.0	16,906.6	4,740.4	11,162.0	5,144.0
2006	45,049.8	2,602.0	18,235.3	4,548.3	11,780.8	5,144.0
2007	45,879.2	2,602.0	17,906.8	4,581.9	12,795.6	5,144.0
2008	46,371.1	2,602.0	17,865.2	4,553.9	13,272.8	5,144.0
2009	47,974.4	2,602.0	17,924.2	4,481.4	14,762.8	5,144.0
2010	48,884.4	2,602.0	18,014.7	4,185.1	15,724.0	5,144.0
2011	48,794.6	2,602.0	18,014.7	3,755.5	15,861.3	5,144.0
2012	48,423.9	2,602.0	17,443.7	3,743.5	15,875.3	5,144.0
2013	48,859.5	2,602.0	17,462.2	3,739.9	16,083.3	5,144.0
2014	48,475.6	2,602.0	16,827.5	3,857.1	15,965.7	5,144.0
2015	48,703.2	2,602.0	16,815.7	3,697.0	16,125.9	5,144.0

Unit: MW
Source: Bureu of Energy (2016)

Table 3. Comparison among UV-C, Chlorine, and Ozone Disinfections

	UV-C	Chlorine	Ozone
Sterilization mode	Physical	Chemical	Chemical
Cost investment	Low	Low	High
Operating cost	Low	Moderate	High
Maintenance cost	Low	Moderate	High
Sterilization effect	Excellent	Good	Unstable
Sterilization time	1-5 sec	25-45 min	5-10 min
Hazards to the human body	Very low	Moderate	High
Residual toxic substance	No	Yes	Yes
Change in water and air	No	Yes	Yes

Source: Hung & Lee (2012)

improvement, and water supply diffusion rate. Taiwan focused on the popularization of water utilization at the initial stage of the operation of tap water. Afterwards, as the living standard of the public was increased, the demand for water quality grew gradually. Therefore, water quality must be continuously improved to meet the standard of developed countries.

Taiwan prohibited using lead pipes for drinking water pipe in 1979. In order to improve the quality of drinking water, water utilities gradually replaced the pipelines with stainless-steel pipelines. Considering the cost of replacing pipelines and household privacy, the replacement engineering was mainly conducted in public water supply lines, while household lead pipes remained in houses, resulting in partial replacement (Chen, 2016). While water treated by waterworks can be directly drunk, after long-term use, the inner walls of delivery pipes become rough, which nourishes bacteria, thus. The public still worry about whether the tap water delivered from the waterworks to houses can be directly drunk, or whether they must boil tap water before drinking. The main fuel sources for boiling tap water include electricity (electric hot water bottle or electromagnetic oven), compressed petroleum gas, and natural gas. For convenient analysis, power consumption is used as the basis of analysis. The following data are obtained from actual experimental results:

Data 1: each person drinks 2 liter (L) water per day on average, and the heat for boiling is described, as follows: Heating a liter water by 1℃ requires about 1 Kcal. As ordinary water temperature is about 20℃, the heat required for heating 2 L water to 100℃ is:

2 × (100 – 20) = 160 (Kcal) (2.1)

Data 2: if each person drinks 2 L water a day, and the water is boiled by an electromagnetic oven, the electric cost is: The calorific value of an electromagnetic oven is:

860 Kcal/kWh(electricity) × 90% (combustion efficiency)
= 774 Kcal/kWh (2.2)
(2.1) is divided by (2.2)
160 (Kcal) / 774 (Kcal/kWh)
= 0.2067 kWh (2.3)

At present, electricity is charged in household units, and the household electricity charging standard is: if the household power consumption exceeds 300 kWh, it is charged at NT$3.5/kWh (note: the exchange rate of US$: NT$ is 1: 30.41 as of 2017/4/18); if the power consumption is not in excess of 300 kWh, it is charged at NT$2.8/kWh. Taiwanese people highly depend on electricity in daily life (e.g. air- conditioners and electric appliances), and for most households the monthly applicable unit of electric charge is NT$3.5/kWh.

Therefore, the electric cost of daily drinking water per capita is:
Electric cost of (2.3)
= 0.2067 kWh × NT$ 3.5/kWh
= NT$ 0.7235 (2.4)
(the two costs are free of electromagnetic oven setup cost, and only include the cost of power consumption)

Data 3:
if each person drinks 2 L water a day, and the water is boiled by an electric hot water bottle, the electric cost is:
A 3 L Zojirushi electric hot water bottle, which consumes 985 kWh per hour, is used for this experiment.
3 L tap water is poured into the Zojirushi electric hot water bottle, which has an upper capacity limit of 3 L, and boiling time is 23 minutes, thus, the corresponding electric cost is:
NT$5/kWh × 0.985 kWh × 23 min/60 min
= NT$1.3212 (2.5)
Therefore, when the daily drinking water per capita (2 L) is boiled by an electric hot water bottle, the electric cost is:

$(2.5) \times \frac{2}{3}$

$= NT\$1.3212 \times \frac{2}{3}$

= NT$ 0.8808 (2.6)

Data 4: the electric cost of boiling daily drinking water per capita (2 L) is:

$\frac{1}{2}$ [Eq. (2.4) + Eq. (2.6)]

$= \frac{1}{2}$ [NT$ 0.7235 + NT$0.8808]

= NT$0.8021 (2.7)

According to (2.7), the annual electric cost of boiling drinking water for 23 million Taiwanese people is:
23 million × NT$ 0.8021/day × 30 days × 12 months
= NT$6.64139 billion/year
System Using UV-lamp Sterilization to Produce Drinkable Tap Water

This system uses solar energy electricity storage as the power source for the UV-C sterilamp, which is very effective at destroying bacteria, viruses, and microorganisms. Its sterilization principle is to damage the structures of bacteria, viruses, microorganism DNA, and RNA to kill them. The best material for the UV-lamp pipe is pure quartz glass cell, which is made of mineral crystal with UV transmittance greater than 80%. Therefore, considering sterilization completeness, the UV-lamp tube must be made of quartz glass cells. From any angle, this disinfection is much better than chlorine or ozone disinfection as shown in Table 3.

Ultraviolet disinfection is the most advanced, effective and economic method for disinfection, as it can thoroughly kill all bacteria, viruses, parasites and algae in a couple of seconds (referring to Table 4). It will not cause secondary pollution or leave any toxic substance, and the sterilized object is non-corrosive, pollution free, and free of residues.

In the drinkable tap water system concept, as designed in this paper, a stainless steel water tower is embedded in the original residential water tower. There are water inlets at the right and left top of the stainless-steel tower. Thus, when the water level in the tower rises to the inlet height, the water flows in the stainless-steel tower and is sterilized by the UV-lamp. And this sterilized drinkable tap water is delivered through the tubule of a cardiac catheter material inserted into the original water pipe to the household. When the drinking water reserved in the stainless-steel tower is lower than the water level, as detected by a sensor, the tap water is supplemented into the water tower till the water level in the tower reaches the right and left water inlet height of stainless steel tower. When the water level outside the stainless-steel tower is lower

Table 4. The 100% Bactericidal Efficiency to the Common Bacterial Virus of the UV-C'S

Type	Name	Time required for 100% kill(s)	Type	Name	Time required for 100% kill(s)
Bacterial	Anthrax bacili	0.30	Bacterial	Tuberculosis (branches) bacili	0.41
	Diphtheria bacili	0.25		Vibrio cholerae	0.64
	Tetanic bacili	0.33		Pseudomonas spp	0.37
	Clostridium botulinum	0.80		Salmonella	0.51
	Dysentery bacillus	0.15		Intestinal fever bacteria	0.41
	Colon bacillus	0.36		Rat typhoid bacillus	0.53
Virus	Adenovirus	0.10	Virus	Flu virus	0.23
	Phagocytic cell virus	0.20		The polio virus	0.80
	Coxsackie virus	0.08		Rota virus	0.52

	Love ke virus	0.73		Tobacco mosaic virus	16
	Love ko virus type i	0.75		Hepatitis b virus	0.73
Mold spores	Aspergillus	6.67	Mold spores	Soft spores	0.33
	Aspergillus	0.73-8.80		Penicillium species	2.93-0.87
	Dung fungi	8.0		Poison penicillium	2.0-3.33
	Mucor	0.23-4.67		Other fungi penicillium	0.87
Water algae	Blue-green algae	10-40	Water algae	Paramecium	7.30
	Chlorella	0.93		Green algae	1.22
	Line worm eggs	3.40		Protozoa	4-6.70
Fish disease	Fung1 disease	1.60	Fish disease	Infectious pancreatic necrosis	4.0
	White spot disease	2.67		Viral bleeding	1.6

*UV Intensity: 30 mw/cm^2

Source: Qinhuangdao Shijiyuan Water Treatment Technology (2012)

than the water level in the stainless-steel tower, the UV-lamp is activated for sterilization as shown in Figure 1(Lai & Chen, 2016). Figure 1 shows that there is a jagged stick on the right and left edges of the stainless-steel tower, thus, the stainless-steel tower can be conveniently lifted to clean the bottom precipitates.

A biomedical material grade tubule made of cardiac catheter material is inserted into the original water pipe to delivery drinkable tap water to kitchen outlets for drinking. This biomedical material is used for making medical appliances used in vivo or in vitro. Basically, these medical appliances can safely, whether directly or indirectly, contact human tissues, body fluid, and blood. In the traditional biomedical material research and development concept, the ideal biomedical materials applicable to the human body must conform with the following conditions: good biocompatibility, inert, non-toxic, non-allergic response, non-carcinogenic, easily procured, and inexpensive. Clinically used biomedical materials can be divided into 4 main classes, metals and alloys, ceramics, polymers, and biological materials (Sung & Chen, 2003). This study uses polymer cardiac catheter material with high inert safety to guarantee the sanitation of drinkable tap water.

System Delivering Aseptic Drinking Water from Residential Water Towers to Households

Lai, Chen, and Chen (2016) used a new model patent "Pipeline Cleaning Device" to solve the poor cleaning effect of known pipeline cleaning devices. The innovative design of this pipeline cleaning device, with a self-propelled image output function, is detailed as follows, and shown in Figure 2. The device contains a cleaning head body, and is provided with a propelling channel, a rotary jetting channel, several spraying channels and a rotary brush head. The rotary brush head can be rotationally located in the front end of the cleaning head body. The propelling channel is located in the cleaning head body, where one end is closed, while the other end is connected to the external surface of the cleaning

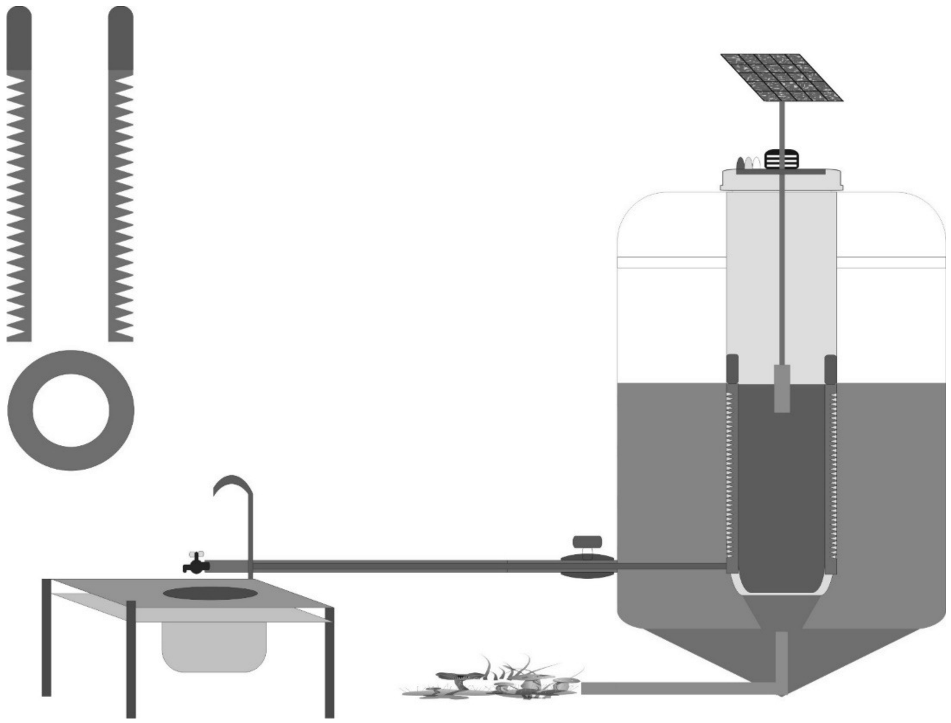

Figure 1. Drinkable Tap Water System Design Structure Diagram

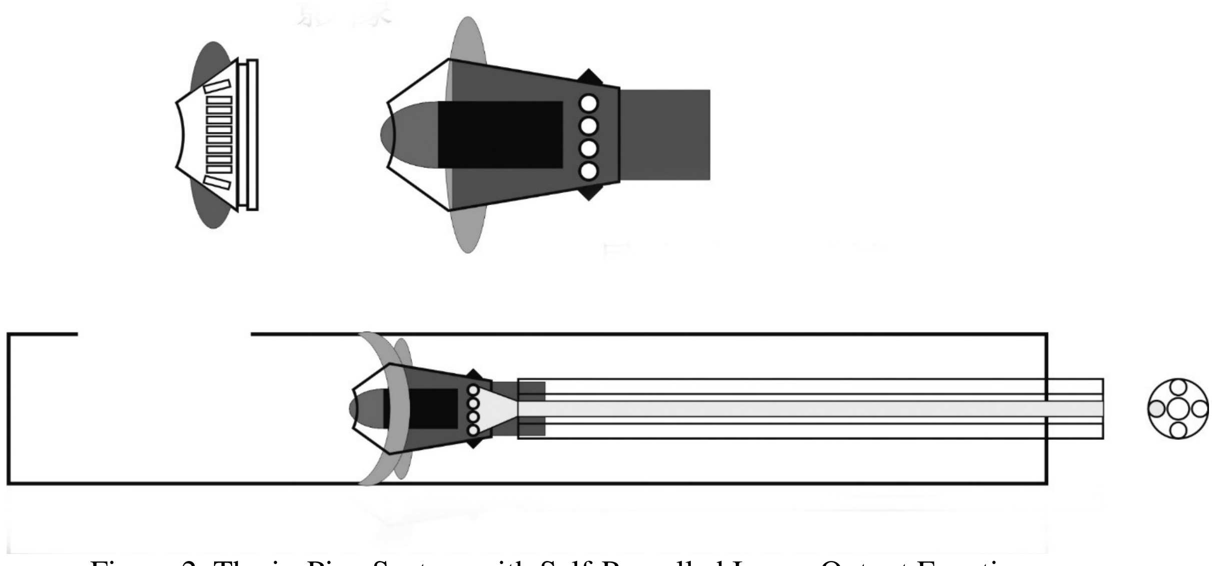

Figure 2. The in-Pipe System with Self-Propelled Image Output Function
Source: Lai, Chen & Chen (2016)

head body. The cleaning head body has a central axis, and the propelling channel is opened along this central axis. Several spraying channels are located around the propelling channel. One end of the spraying channel is connected to the circumference of the cleaning head body. There is a blade on the front end outer edge of the cleaning head body. The pipeline cleaning device has several pipe fittings at the back end of the cleaning head body, where one end is connected to the propelling channel, the rotary jetting channel, and several spraying channels. This pipeline cleaning device also contains a container for holding fluid. The other end of the pipe fittings is connected to the container, and a controller controls the supply or recovery of the fluid in this container. This pipeline cleaning device contains a monitoring system, which has a camera coupled to a control host connected to a display. The cleaning head body is provided with a holding slot, which is open on the front-end face of the cleaning head body to hold the camera, and the cover body is made of perspective material. This holding slot is not connected to the propelling channel, rotary jetting channel, or spraying channels. And, the bottom of the holding slot is closed. The rotary brush head comprises a cover body and a brushware. The inner surface of this cover body forms a holding chamber, where the front end face of the cleaning head body adjoins the holding chamber, and the brushware is connected to the outer surface of the cover body. The cleaning head body has a central axis, where one end of the rotary jetting channel is connected to the holding chamber, and deviates from the central axis. There are several lugs on the inner surface of the cover body, which are arranged at annularly angular intervals centering on the central axis. The front end of cleaning head body has an annular groove, and there are several grabs on the circumference of the cover body to catch this groove.

Conclusion

Taiwan is confronted with economics growing side effects resulted from continuous energy shortage and the greenhouse effect, as typhoons frequently occur, and disasters caused by rain and wind are increasingly severe. Yellow tap water after a typhoon or afternoon thundershower has aroused public indignation. The first cause for public indignation is the shortage of drinking water. While using yellow tap water as non-drinking water is fairly acceptable, people cannot live without drinkable tap water. If various households mount the solar energy electricity storage UV-lamp sterilized drinkable water storage tank, as designed by this paper, in their water towers, the tubule made of cardiac catheter material will convey the aforesaid drinkable tap water through the original water pipe (the big pipe contains a tubule) to various kitchens. As the supporting duration of the aseptic drinkable tap water reserve exceeds the number of days required for the government to urgently deal with yellow tap water, public complaints regarding yellow tap water events will be greatly re

The aseptic tap water system, as designed in this paper, has the following advantages: (1) saving energy (tap water can be drunk directly without boiling) (2) the tubule material embedded in the original water pipe will not deteriorate to breed bacteria under the effect of temperature difference (3) the stainless steel water storage tower embedded in the original water pipe can be lifted out along the gears for cleaning bottom precipitate (4) this aseptic drinking water system avoids from drinking yellow tap water, as resulted from typhoons or thundershowers.

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SCENARIO ANALYSIS OF FATAL CONSTRUCTION ACCIDENTS – A TAIWANESE PERSPECTIVE

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Abstract

This study investigated 298 fatal construction occupational accidents (FCOA) to realize which common attributes contribute to fatal accidents in the industries. The scenario analysis method is used to gain insight into the connection of causes of fatal accidents. The Cramer's V and Phi (φ) is used to determine the level of correlation of key variables related to FCOAs. The statistical analysis was able to identify the key variables of significance in the event chain which can be used to inform accident prevention strategies. It is found that the building construction industry accident prevention strategies need to focus on the job types of mortar and painting, roofing installation and maintenance, and steel structure engineering. The hazard type of greatest significance is falls from height and collapses associated mediums of scaffolding, bracing, roofing, and cavity & hole. The civil engineering sector occupational accident prevention strategies need to focus on

the job types of construction apparatus and transport equipment use as well as miscellaneous jobs. For accident type, miscellaneous accident types and object collisions need to be the focus on prevention strategies. The associated accident mediums of greatest concern are construction apparatus, transport equipment and environment.

Keywords: Scenario analysis, fatal construction occupational accidents (FCOA), accident prevention strategies, building construction, construction industry

Introduction

Taiwan experiences a significant rate of workplace accidents, with a total of 1,874 fatalities recorded between 2000 to 2011. The building construction and civil engineering industry accounted for 44% (822) of all fatal incidents recorded during this period (Chen et al. 2013). Workplace injuries, especially fatalities have a significant social and economic impact *(add detail on impacts of work place incidents to the economy)*. To address the systemic causes of fatal incidents in construction industry safety there needs to be a fundamental understanding of root causes, repetitions (if any), and responsibilities of serious accidents through in depth analysis of past incidents.

Occupational safety management issues can be classified according to a range of sectors, project types and tasks, potentially obscuring underlying factors which contribute to fatalities such as unsafe actions and other ineffective safety controls to ensure worker safety. Concealment of causal factors as well as a lack of accurate knowledge and poor attitudes towards organizational safety culture may further exacerbate the unacceptably high rate of occupational fatalities in Taiwan. Fatal construction occupational accidents typically result from an amalgamation of multiple events and factors which may not be readily apparent without robust analysis of contributing situational factors. Relevant literature on the topic of work place accidents frequently rely on statistical methods to identify and categorize common root causes of fatal construction occupational accidents (Ling et al. 2009; Chen et al. 2015).

Investigating the common characteristics of fatal construction occupational accidents in depth is useful for informing targeted prevention strategies to avoid future reoccurrence of similar accidents. Aggregated post-accident statistical analysis of known high-risk groups can be applied to determine the degree of influence of a range of factors which contribute to fatal construction occupational accidents. Scenario analysis is a useful method to identify underlying systemic causes of such accidents to apply to the statistical analysis. Using SPSS software package, this study examines common factors of fatal construction occupational accidents in Taiwan’s building construction and civil engineering sectors between 2003 to 2012. The study is based on analysis of frequent accident characteristics, mediums and circumstances, to better understand common causes of workplace accidents to develop effective programs to improve worker safety.

Previous Studies

Understanding how accidents occur is crucial in terms of distinguishing these factors' significance. Kemei and Nyerere (2016) classified accident causation models regarding how accidents happen into four generations. The first generation holds a person's traits and unsafe behavior as responsible for accident. The second generation theories (domino theories) conceptualize a chain of sequential events resulting in an accident and call these events as dominos. The third generation (injury epidemiology models) holds that accident prevention efforts do not necessarily result in accident control in a working system. The fourth generation (system approach to accident causation) was emerged to respond the challenge of maintaining safety in increasingly complex work system. Im et al. (2009) explores the characteristics of fatal occupational injuries in Korea's construction industry and comparing the causes in various occupations within that industry. They found that falling was the most frequent cause of fatal injuries. Deaths due to structural collapse and electric shock were much higher than that in other industries. They concluded that a reduction in the construction industry alone will substantially contribute to an overall reduction of occupational injuries in Korea.

Via the data between years 2000 and 2007 in Taiwan, Cheng et al. (2010) analyze the characteristic factors responsible for occupational accident occurrence for small construction enterprise using several statistics methodologies. Their research includes that occupational accidents tend to occur (1) during the worker's first day at the workplace, (2) when the construction project has an excessively low health and safety management, (3) when employer did not provide personal protection equipment to the workers, (4) when personal protection equipment was not correctly used, and (5) when workers failed to adopt safeguards or ignored hazard warning signs in the workplace. Yilmaz (2014) investigate causes and results of occupational accidents occurred in Turkey's construction sites. The major reasons for construction accidents include: *being hit by dashing and flitting objects*, *being hit by objects*, *falling objects*, and *being stung by something*. Injuries due to occupational accidents include: incision, exposure to metal burrs, contusion, transient loss of vision, trauma and perforation. The study also concludes that construction safety performance in Turkey is much worse than developed countries. Dumrak (2013) developed a conceptual model, considering personal characteristics (age, experience, gender and language background) and work-related factors (size of organization, project size and location, mechanism of accident and body location of the injury), to analyze 24,764 construction accidents during 2002-2011 in South Australia. They found that Factors such as *time of accident*, *day of the week and season* were not strongly related to accident severities.

Although the causes of accidents in the construction industry have been extensively studied, fatal construction occupational accident remains an underexplored area. The study aims to explore the characteristics of fatal construction occupational accidents to provide more evidence for the limited empirical investigations on fatal construction occupational accidents.

Research Hypotheses

Case data used in this study are from the Institute of Labor's 298 fatal occupational accident investigation reports from the Taiwanese building construction and civil engineering sectors (Institute of Labor, 2013). The reports covered three regions: Northern, Central, and Southern Taiwan. The review of accident investigation reports, identified 26 key variables across three categories (basic victim information, accident characteristics, and causal factors) which are common across the reported incidents. The scenario analysis is used to gain insight into the causes of fatal accidents. In the scenario analysis, the event-chain method is used to create a framework for key factors and the related variables for the entire accident. These accident variables were subjected to Cramer's V analysis and φ analysis to determine the level of correlation of accident variables and the significance of correlation. The results provide insight to significant factors in situational model related worksite accident occurrence. The results can be used to define categories of industrial sector, job types, accident types and accident mediums to draw attention to key causes behind such accidents.

Accident characteristics

The breakdown of information for analysis was completed using the following hierarchy; industrial sector, job type, workplace fatal type and accident medium. The descriptions of the categories are as follows:

1. Industrial sectors: The key industrial sectors can be categorized as (1) Building Construction sector and (2) Civil Engineering sector.

2. Job types: Previous incident reports show accidents occurred when the respective workers were engaged in work involving the following tasks: (1) Foundation, (2) formwork, (3) rebar, (4) scaffolding, (5) concrete, (6) mortar and painting, (7) tiling, (8) plumbing & sewage, (9) construction equipment, (10) roofing, (11) steel work, (12) finishing, (13) cleaning, (14) movement & migration, (15) demolition, (16) management & monitoring, (17) inspection, (18) waterproofing, (19) other.

3. Accident types: The Council of Labor Affairs in Taiwan classes hazard types as follows (include ref): (1) Falls (from height)/collapses, (2) struck by falling material (3) electricity/heat, (4) drowning, (5) others (e.g., transport accidents, slips/trips/falls, treads, pernicious/toxic substances, fires, explosions and miscellaneous hazards).

4. The 12-different accident medium groups selected for this study are shown in Table 1.

Accident Cause Categories

Construction sites are inherently complex with many tasks and operations occurring simultaneously, as well as conditions and operations changing day to day. However, there are several underlying causes common to construction workplace accidents. Previous studies related to unsafe conditions were reviewed to categorize frequent factors related to accidents in building construction and civil engineering (Liao et al. 2013).

Table 1 Classification of frequent accident mediums

Types of accident mediums	
1.High-voltage conductor	2.Motor-carry machines /transportation
3.Loading Machinery/tools	4.Electric wire
5.Hanger & cradle	6.Scaffolding
7.Cavity & hole	8.Roofing
9.Construction apparatus	10.Pernicious/toxic substances
11.Environment	12.Others

The review of past accidents reveals that common indirect causes of unsafe worksite conditions can be attributed to a range of actions or events. According to Abdelhamid and Everett (2000) the cause of worksite accidents can be attributed to management actions; unsafe acts of worker or coworker; non-human-related event(s); an unsafe condition which is a natural part of the initial construction site conditions.

Isolating the causes of worksite accidents is difficult and become even more difficult for fatal accidents (Cattledge et al., 1996). To better understand the frequency of conditions associated with worksite accidents in this study, several categories and sub- categories were developed to categorize unsafe conditions. Based on the 298 fatal construction occupational accidents in the Taiwanese construction industry, the frequency of incidents associated with causal categories is shown in Table 2.

Data Analysis

Descriptive statistics

The characteristic variables applied to accident analysis can provide insight into occupational accidents in the building construction and civil engineering sectors through revealing statistical patterns. For this study, the variables selected were associated with industrial sector, job type, accident type and accident medium. Cramer's V provides a measure of the degree of correlation between two selected types of variables. The value ranges between 0 and 1, with values closer to 1 indicating a higher degree of correlation. The Phi (φ) factor must be restricted within a 2x2 cross-tab, and has a value between ±1.0, to show the degree of correlation between two factors. When calculating the Phi (φ) coefficient, each factor is re-encoded in binary. If the value for φ is positive, the factor variables are positively correlated together. If the value of φ is negative, the factor variables are negatively correlated (Hair et al., 2010).

In the scenario analysis model, an event-chain method is used to create a framework for analysis of key factors for an accident. Scenario analysis is a method to obtain the accident causes for selected incidents. Analysis of Cramer's V and Phi (φ) is a powerful method for understanding accident causal factors through identifying the correlations

Table 2. Unsafe Conditions categories and Frequencies (ranking within Category)

Category	Sub-Category	Inci-dents.	%
Prevention control and warning signs (28%)	No warnings or signs	32	14
	Insufficient prevention measures	180	77
	Inadequate supervision	19	8
	Unclear warnings or signs	2	1
Adverse operating environment (23%)	Poor lines of movement	5	3
	Poor ventilation	1	1
	Materials poorly positioned and stacked	11	6
	Falling risk, situated near opening	82	43
	Situated beneath hanging objects	10	5
	Potential for collapse	22	12
	Equipment operation area	14	7
	Other adverse environmental conditions	22	12
	Falling objects or earth	8	4
	Electrocution risk	9	5
	Poor sightlines or illumination	5	3
Facilities, methods, and procedures (30%)	Lack of safety equipment	39	16
	Defective safety equipment	37	15
	Insufficient facilities	31	13
	Poor facilities maintenance	3	1
	Abnormal operating conditions	14	6
	Poor facilities design	44	18
	Improper operation, insufficient oversight	74	30
	Inappropriate use of facilities	1	0
Health training and awareness (1%)	Insufficient experience	0	0
	Distracted behavior	0	0
	Poor health	2	29
	Insufficient expertise	1	14
	Lack of safety training	4	57
Poor personal prevention (18%)	Failure to wear proper personal protective equipment	31	21
	Failure to wear personal protective equipment	20	13
	Failure to enforce workers requirement to wear correct personal protective equipment	98	66

between selected accident factors of interest. For scenario analysis, the information aides in clarification of systemic causes of accidents and guide implementation of corresponding countermeasures. This study aggregated the findings of 298 fatal construction occupational accident reports. In terms of accidents by industry, the majority were related to civil engineering projects, with 178 incidents (59.7% of the total) were attributed to civil engineering projects, the remaining incidents occurred area associated with building construction projects.

Scenario analysis

This study employs scenario analysis as proposed by Drury and Brill (1983) to screen for causal factors for serious occupational accidents, and then uses Altonen (1996) incident chain approach to connect accident factors in a "Job Type – Medium – Hazard Type" model of fatal construction occupational accidents. Cramer's V and φ analysis is used as tool to determine the level of correlation between the selected variables of interest. Due to the limited sample size available to the study, a five percent significance level ($P<0.005$) was considered most suitable as the significance level to create an "Industrial Sector – Job Type – Hazard Type – Accident Medium" model. Figure 1 shows the incidence and percentiles for significantly correlated factors.

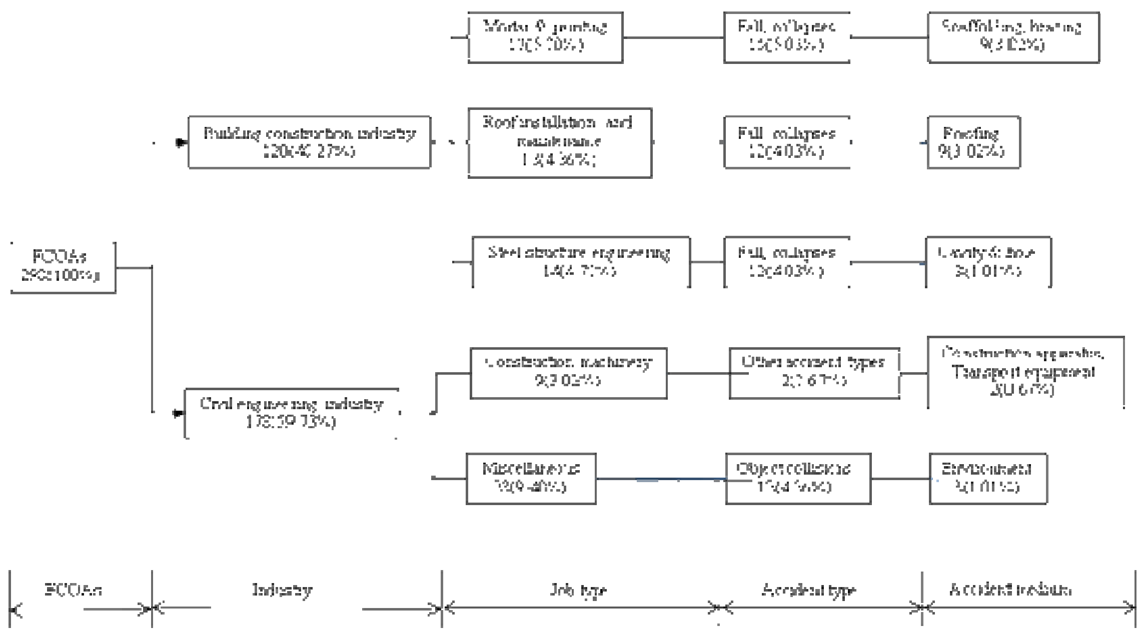

Figure 1. Fatal construction occupational accident scenario analysis and relationship

Cramer's V coefficient analysis

A detailed breakdown of job types being performed at the time of incident shows that accidents associated with formwork were the most frequent job type, accounting for almost 12% of the total (35 incidents), the next most frequent were tasks associated with lifting, transport, removal or moving (31 incidents, 10.4% of the total). In terms of accident type, most incidents were associated with falls or collapses (171 incidents, 57.4%), followed by object collisions (89 incidents, 29.9%). The most frequent accident medium is, cavity and hole accounting for 19.5% of all incidents (58 incidents), the next most frequent construction mediums included construction apparatus (55 incidents, 18.5%), followed scaffolding and bracings (43 incidents, 14.4%).

Results of Cramer's V coefficient, analysis (Table 3,) show that accident type and accident medium displayed the strongest correlation (V=0.654, P=0.000).

The cause of the strong correlation is likely due to multiple accident types associated with a specified accident medium. Conversely, the weakest correlation was sector type and hazard type (V=0.300, P<0.01). The weak correlation is due to many different hazard types being common to both building and civil engineering sectors. For example, consider the hazard type of falls or collapses, there are numerous operations in both building construction and civil engineering sections are prone to accidents related to falls or collapses.

Table 3. Cramer's V analysis of job type, accident type and accident medium

Accident characteristic variables	Sector	Job type	Hazard type
Job type	0.483(0.000) **		
Accident type	0.300(0.000) **	0.334(0.000) **	
Accident medium	0.475(0.000) **	0.340(0.000) **	0.654(0.000) **

Notes: from left to right represent the Cramer's V value and significance level; *: $p < 0.05$; **: $p<0.01$)

Phi (φ) coefficient analysis

Phi (φ) coefficient factor analysis results for correlations between industrial sector and job type, industrial sector and accident type, industrial sector and accident medium, job type and accident type, job type and accident medium, and accident type and accident medium are shown in Table 4.

Following the scenario model to screen the main causal factors from the results of the Phi value analysis shown there are incident chains of importance in both the building construction and civil engineering sectors. For the building construction industry prevention occupational accident strategies need to focus on the job types of mortar and painting, roofing installation and maintenance, and steel structure engineering. The hazard type with the greatest significance for the job types of greatest significance is falls and collapses. The key associated mediums of interest are scaffolding, bracing, roofing, and cavity and hole.

The results for the civil engineering sector show that occupational accident prevention strategies need to focus on the job types of construction apparatus and transport equipment use as well as miscellaneous jobs. For the category of accident type, miscellaneous accident types and object collisions need to be the focus of prevention strategies. Associated accident mediums of greatest concern are, construction apparatus, transport equipment and environment.

Table 4. Phi analysis of occupational characteristics associated with fatal construction occupational accidents in the building construction and civil engineering sectors

Accident characteristic variable		Industry sector		
		Building construction	Civil engineering	
Job type	Mortar & painting	0.213(0.000) **	-0.213(0.000)	
	Construction machinery	-0.145(0.012)	0.145 (0.012) *	
	Roof installation and maintenance	0.218(0.000)**	-0.218(0.000)	
	Steel structure engineering	0.135(0.020) *	-0.135(0.020)	
	Miscellaneous	-0.229(0.000)	0.229(0.000) **	
Accident	Falls, collapses	0.293(0.000)**	-0.293(0.000)	
	Object collisions	-0.237(0.000)	0.237(0.000) **	
Accident medium	Construction apparatus, transport equipment	-0.175(0.002)	0.175(0.002) **	
	Scaffolding, bracing	0.189 (0.001) **	-0.189(0.001)	
	Roofing	0.268(0.000) **	-0.268(0.000)	
	Environment	-0.214(0.000)	0.214(0.000) **	
		Accident type		
		Falls, collapses	Object collision	Other accident types
Job type	Mortar & painting	0.191(0.001) **	-0.156(0.007)	-0.072(0.379)
	Construction machinery	-0.086(0.177)	0.013(1.000)	0.120(0.039) *
	Roof installation and maintenance	0.167(0.004) **	-0.117(0.045)	-0.058(0.611)
	Steel structure engineering	0.191(0.001) **	-0.128(0.027)	-0.072(0.379)
	Miscellaneous	-0.185(0.001)	0.123(0.034) *	0.056(0.406)
Accident medium	Construction apparatus, transport equipment	-0.148(0.011)	0.076(0.218)	0.222(0.005) **
	Scaffolding, bracing	0.122(0.035) *	-0.018(0.762)	-0.104(0.086)
	Cavity & hole	0.407(0.000) **	-0.321(0.000)	-0.125(0.029)

	Roofing	0.233(0.000) **	-0.179(0.002)	-0.042(0.704)
	Environment	-0.275(0.000)	0.160(0.006) **	-0.066(0.616)
	Other medium	-0.109(0.076)	-0.063(0.443)	0.219 (0.009) **

		Job type				
		Mortar & painting	Con-struction machin-ery	Roof in-stallation & mainte-nance	Steel struc-ture engi-neering	Other
Accident medium	Construction apparatus, transportation equipment	0.003 (1.000)	0.346 (0.000)**	-0.049 (1.000)	-0.060 (0.609)	0.092 (0.132)
	Scaffolding, bracing	0.213 (0.001)**	-0.072 (0.367)	-0.095 (0.140)	-0.043 (0.752)	-0.010 (1.000)
	Cavity & hole	0.023 (0.779)	-0.087 (0.214)	-0.036 (0.744)	0.153 (0.020)*	-0.024 (0.683)
	Roofing	-0.098 (0.146)	-0.061 (0.604)	0.465 (0.000)**	0.109 (0.072)	-0.116 (0.056)
	Environment	-0.074 (0.378)	0.034 (0.452)	-0.060 (0.609)	-0.074 (0.378)	0.141 (0.031) *

Notes: Phi value and significance level, (*: p <0.05; **: p <0.01) are shown from left to right and top to bottom

Aggregated accident causes for key situations

Table 5 is a sample of summary of the frequency and percentage of various accident factors for fatal construction occupational accidents, as described by the significance model. For example, taking the example of the nine fatal construction occupational accidents classified in the building construction trade, 40 incidents of unsafe conditions were found in terms of mortar & painting operations, falls & collapses, and scaffolding & bracing. Based on the Pareto Principle (where causal factors account for the first 20% of total cases), Table 6 recaps the corresponding three key accident causes, along

Table 5. Summary of unsafe conditions contributing to fatal accidents

	Building Construction Sector						Civil Engineering Sector			
Unsafe condition	Mortar & Painting Operations-Falls & Collapses						Construction equipment-Others - Loading / Transporta-tion		Foundation - Accident Collision-Environ-ment	
	Scaffolds & bracing		Roofing		Cavity & hole					
	Incident	%	Incident	%	Incident	%	Incident	%	Incident	%

No warnings or signs	0	0	0	0	0	0	1	33	0	0
Insufficient prevention measures	3	8	8	30	2	20	0	0	3	30
Falling risk, situated near opening	7	18	1	4	2	20	0	0	0	0
Potential for collapse	0	0	0	0	0	0	0	0	2	20
Other adverse environmental conditions	1	3	0	0	0	0	1	33	0	0
Falling earth or objects	0	0	0	0	0	0	0	0	2	20
Lack of safety equipment	8	20	0	0	1	10	0	0	0	0
Defective safety equipment	2	5	1	4	1	10	0	0	0	0
Insufficient facilities	1	3	4	15	0	0	0	0	0	0
Poor facilities maintenance	1	3	0	0	0	0	0	0	0	0
Abnormal operating conditions	0	0	0	0	0	0	1	33	0	0
Poor facilities design	7	18	5	19	1	10	0	0	0	0
Improper operation, insufficient oversight	2	5	0	0	0	0	0	0	2	20
Failure to wear proper personal protective equipment	1	3	2	7	0	0	0	0	0	0
Failure to wear personal protective equipment	2	5	1	4	1	10	0	0	0	0
Failure to force worker to wear protective equipment	5	13	5	19	2	20	0	0	1	10
Total	40	100	27	100	10	100	3	100	10	100

Table 6. Accident causes and corresponding prevention measures of 40 incidents

Indus-	Job	Acci-	Acci-	Incidence of unsafe conditions	Key accident causes summarized by database	Corresponding prevention measurement to key accident cause

				Identifier	Incidents	Percent-		
Building Construction Industry	Mortar and Painting	Falls, collapses	Scaffolding, bracing	uc-3-A	8	20	1. For roofs at elevations greater than 2 meters, openings and scaffolding work areas present a fall risk due to lack of railings, coverings and safety nets. 2. Scaffold footboards measure less than 40 cm in width, and the spacing between footboards is less than 3 cm. 3. Failure to properly use safety harnesses, hard hats and other protective equipment.	1. For roofs at elevations greater than 2 meters, openings and scaffolding work stations should be equipped with railings, covers or safety nets. 2. Where workers are exposed to falls greater than 1.5m, equipment must be provided to allow for safe ascent and descent. 3. For work which exposes workers to falls of 2m or greater, appropriate countermeasures must be implemented to ensure safety. 4. For framework done at elevations of 2 m or more, the width of the scaffold footboards should be at least 40 cm, and the spacing between footboards is less than 3 cm. 5. Where work is done on scaffolds 2 m or more in height, workers must wear safety harnesses, hard hats and other necessary protective equipment.
				uc-2-D	7	17.5		
				uc-3-F	7	17.5		
				uc-5-C	5	12.5		

Table 7. Summary of accident causes for nine cases

#	Accident causes	No.	Ratio
1	Fail to establish practice codes safety and heath	8	89%
2	Fail to set up safety and health management personnel	7	78%
3	Fail to implement safety and health training	9	100%
4	Fail to implement self-inspection	9	100%

with the corresponding five prevention countermeasures. An example of the basic accident causes for nine cases presenting in Table 7, indicates that worker safety management is not properly implemented by the authority. Comprehensive analysis results show that the building construction industry entails work at high elevations, exposing workers to accidents involving falls and collapses, and requiring additional attention to accident mediums including scaffolding, bracings, roofing, and openings, along with improved labor safety management.

Conclusions

From review and analysis of 298 fatal construction occupational accidents reports taken from worksite incidents in the building construction and civil engineering sectors from 2002 to 2012 there are certain factors in the scenario model which are notably significant. Using statistical analysis, the study was able to group incidents by 26 key variables in three key categories. The three key proposed categories based on the scenario model in combination with the incident chain approach to connect accident factors in a "Job Type – Medium – Hazard Type". Through coding and detailed statistical analysis (Cramer's V and φ analysis) the study identified the incidence of a number of variables common to fatal accidents in the building construction and civil engineering industries of Taiwan.

For the building construction industry, there is a clear high-risk scenario model for job types of mortar and painting, roof installation and maintenance, and steel structure engineering. These activities feature the greatest incidence of accidents characterized by falls and collapses, with accident mediums including scaffolding, bracings, roofing, and cavity & hole. For the civil engineering sector, the scenario is not as clear. The highest risk job items include construction machinery operation and miscellaneous items, along with accident types including miscellaneous accidents and object collisions, and accident mediums including construction apparatus, transportation equipment, and environmental conditions. With such a high importance placed on miscellaneous tasks for the civil engineering sector there is a major challenge to realize the common factors in the category due to board nature of activities contained within.

Through the [building construction sector – mortaring & painting – falls & collapses – scaffolding & bracings] case, the occupational accident model summarizes three key accident causes: (1) lack of safety railings, covers and nets near openings in scaffolds, (2) work stations measuring less than 40 cm in width and fail to lay plank which ought to be bonded closely, and (3) failure of workers to properly use safety harnesses, hard hats and other protective equipment. Statistical analysis of accident causes show that relevant operational institutions have failed to institute adequate labor safety management measures.

Further research on the components of the miscellaneous categories to better understand the common causal factors for fatal construction occupational accidents in the miscellaneous task categories. It is also suggested to introduce value engineering (VE) functional analysis, with input from experts in VE and labor safety to determine the degree of association, along with functional importance and accident prevention effectiveness, for the vetting and classification of accident prevention measures, and thus enhance the value of occupational accident case data.

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