Journal of Asian Concrete Federation
Vol. 2, No. 2, Dec. 2016, pp. 95-101
ISSN 2465-7964 / eISSN 2465-7972
http://dx.doi.org/10.18702/acf.2016.12.2.2.95

Fire resistance calculation of existing concrete structures using modified Tabulated Data Method

Duinkherjav Yagaanbuyant*and Khishgee Radnaabazar

(Received: March 21, 2016; Accepted: October 24, 2016; Published online: December 31, 2016)

Abstract: During its service operation, a gradual reduction of the material strength and the load bearing capacity of a concrete structure is expected and the same is also true for its fire resistance capacity. Although it is needed to estimate the remaining service life of the structure considering this reduction of fire resisting capacity for the design for the building renovation or expansion, the proper calculation guidance or the methodology still doesn't exist in Mongolian national building code. This paper discusses the assessment of the actual fire resistance capacity of the existing pre-cast concrete industrial/residential buildings that were built during 1962-1999 in Ulaanbaatar, Mongolia. Modifications to the Tabulated data method are offered based on the findings of the study. The estimated values of the actual fire resistance limit of PC walls and slabs are proposed in tables and graphical forms that can be used in the calculation of the actual fire resistance of the existing buildings in use to determine renovation requirements.

Keywords: pre-cast concrete, reinforcement, fire severity, inspection, Tabulated data method.

1. Background

During its service life of a concrete structure, a gradual deterioration of structural performance including a reduction of its fire resistance performance is expected. When the deterioration is significant, the fire resistance capacity assessment of an existing structure becomes one of the requirements for further renovation and expansion. Roitman has studied the fire resistance of existing buildings in terms of effects of the reinforcement corrosion and the damages to concrete, but the service life of the structure has not been considered [1]. In this paper, the operational condition and the service life of structures are taken into account in the assessment of the fire resistance capacity of concrete structures for their further occupation.

In general the deterioration of the industrial buildings can be often of major concern. But from recent studies by the authors for the residential buildings, even though their operational conditions are not as severely reduced as those of the industrial buildings, the accumulated deterioration in the structures through years can have significant adverse effects on its fire resistance capacity and therefore should be included in the design of the building expansion and/or the renovation. In recent years such consideration of structural deterioration reducing its fire resisting capacity has become even more important due to the increased demand of building expansion through addition of stories and re-planning in urban areas in Ulaanbaatar. As the currently used Mongolian national building code doesn't include a proper guideline to estimate this, the authors offer a modification to currently used Tabulated data method of the fire resistance based on the actual service condition and the service life of the existing concrete structures.

2. Fire resistance assessment methods

The fire resistance of reinforced concrete structures can be assessed experimentally through fire tests of the actual structures or analytically by engineering calculations [1~3]. A brief summary is given below.

2.1 Experimental Method

The results of the fire tests on the actual structures are most reliable and accurate for the assessment of the fire resistance capacity. Usually the fire tests are carried out using a fire chamber equipped with the load testing machine and the furnace. Calculation tables or tabulated data as developed from

Corresponding author Duinkherjav Yagaanbuyant is a Professor of the School of Civil Engineering and Architecture, The Mongolian University of Science and Technology, Ulaanbaatar, Mongolia.
Khishgee Radnaabazar is an Associate Professor of the School of Civil Engineering and Architecture, The Mongolian University of Science and Technology, Ulaanbaatar, Mongolia.

the multiple test data to be used for the structural assessment based on the structure's geometry, material type, and loading and boundary conditions. The disadvantages of the fire test are time, cost, energy consumption, and a need of special facility and specialists which make the analytical methods more favorable. The fire tests better be pursued for selective structural elements or assemblages, a new type of material or design of structural elements.

2.2 Analytical Methods

The analytical method of the fire resistance capacity determination of a structure can be carried out in two steps: thermal analysis and static analysis. The thermal analysis determines the developed temperature field across the cross section of the structure and the static analysis determines the load bearing capacity of the structure under loading taking into account the effects of the changes of the material properties due to elevated temperatures. In general, the fire resistance capacity estimation is carried out by incremental iteration method from the initial ignition of the fire through thermal and static analysis steps. In Fig. 1, the strength reduction over time is shown as an example of static analysis result. The fire resistance limit τ_u, is considered as the time period of the ultimate load bearing capacity reduction of the structure to its critical state F_{act}. In Fig. 2, a typical thermo-mechanical scheme of a RC structure during fire exposure is shown.

In BS EN 1992-2, three fire resistance assessment methods are suggested: (1)Tabulated data method, (2) Simplified calculation method, and (3) Advanced methods. It is also specified that the Tabulated data method can be used as an appendix to the national standards.

In Russian and Mongolian practice, the experimental method and above mentioned three analytical methods are both used for assessment of

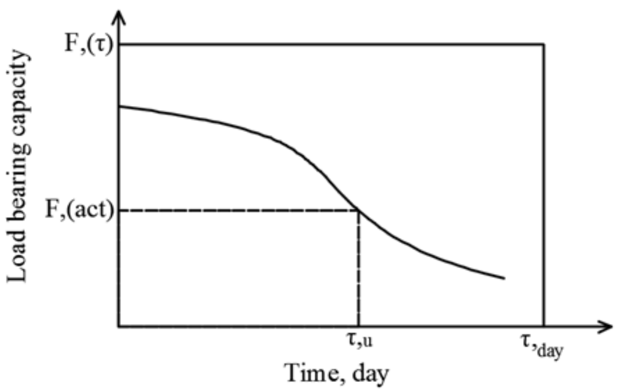

Fig. 1 – Typical scheme for the assessment of fire resistance by strength reduction criterion at elevated temperature [2]

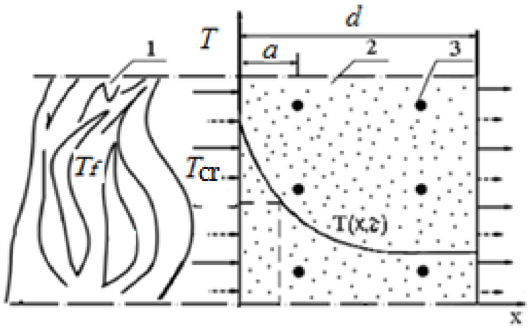

Fig. 2 – Typical thermo-technical scheme: 1-fire, 2-concrete, 3-reinforcement, d-member width, *a*-concrete cover depth, T_{cr}-critical temp., T_f -fire temp., $T_{x,\tau}$-temp. profile [2]

the structural fire resistance and, for this purpose, the guidelines and procedures of ref. [7~9] are followed. Currently, in Mongolia, the most frequently used method for the fire design of a new building is the Tabulated data method. But it cannot be used for the design for the building expansion, addition of stories in an existing building, replanning of the existing building. In the Tabulated data method, the resistance limit of reinforced concrete slabs and walls is given based on element thickness and concrete cover depth of reinforcement, but in the case of an existing building in use, actual values of concrete cover and thickness could be reduced due to defects in concrete cover and reinforcement corrosion. Therefore certain modifications are required in the use of the tabulated method for the actual fire resistance estimation of the existing buildings in use.

The Simplified calculation method is based on applying the strength reduction factors at elevated temperatures to simplified cross-sections for which the thermal gradient through the structural member is known or, alternatively, by utilizing a reduced cross-section whereby a damaged zone is ignored in the calculation and only the residual undamaged part is included in the calculation of the resistance [13]. The relevant parameters for the Simplified calculation method are taken from the information supplied on the material properties of the structural component.

Generally the Advanced method includes the numerical models for heat transfer from the fire into the structural member and the mechanical response models to determine the structural response of the member or members to the effects of both mechanical and thermal actions. General guidance is available in the European Standard on the use of the Advanced calculation models for the design of concrete structures. Unlike the Tabulated data

Table 1 – Fire resistance limit of reinforced concrete slabs [7]

Concrete type and slab characteristics		Slab thickness t and concrete cover depth of rebar a, mm	Fire resistance limit, min						
			15	30	60	90	120	150	180
Normal	Slab thickness	t	30	50	80	100	120	140	155
	One way or two way, $l_y/l_x \geq 1.5$	a	10	15	25	35	45	60	70
	Two way, $l_y/l_x < 1.5$	a	10	10	10	15	20	30	40

NOTE: Normal weight concrete (2,000-2,600 kg/m^3)

Table 2 – Fire resistance limit of load bearing walls [7]

Concrete type	Wall thickness t_c and concrete cover depth of rebar a, mm	Fire resistance limit, min					
		30	60	90	120	150	180
Normal	t_c	100	120	140	160	200	240
	a	10	15	20	30	30	30

method, the Advanced method is suitable for any type of fire exposure. However, knowledge on the degradation of the material properties for the particular fire exposure condition is required.

2.3 Tabulated Data Method

From the guidelines of ref. [7,8], the fire resistance of reinforced concrete slabs and walls based on concrete type, element thickness, and concrete cover depth of reinforcement are shown in Table 1 and Table 2. It must be noted that, in the Tabulated data method, the resistance limit of reinforced concrete slabs and walls is given based on element thickness and concrete cover depth of reinforcement, but in the field, other effects such as defects in concrete cover, reinforcement corrosion, and concrete strength actually play important roles too [1,10].

3. Actual fire resistance of existing PC residential buildings

From the tabulated data, the design limit of fire resistance $\tau^{n}_{f,r}$ can be determined. But for the existing building in use, the actual fire resistance of the structure $\tau^{s}_{f,r}$ is lower than this design value due to the deteriorated state of the structures. The actual fire resistance of the structure $\tau^{s}_{f,r}$ can be determined by Eq. (1), where C_1 is the reduction factor of the service life and C_2 is the reduction factor of the actual service conditions [1].

$$\tau^{s}_{f,r} = \tau^{n}_{f,r} \cdot C_1 \cdot C_2, \quad (1)$$

The reduction factor C_2 that accounts the service conditions can be expanded further as $C_{2,1}; C_{2,2}; \ldots C_{2n}$ taking into account specific characteristics of the condition such as concrete strength, corrosion,

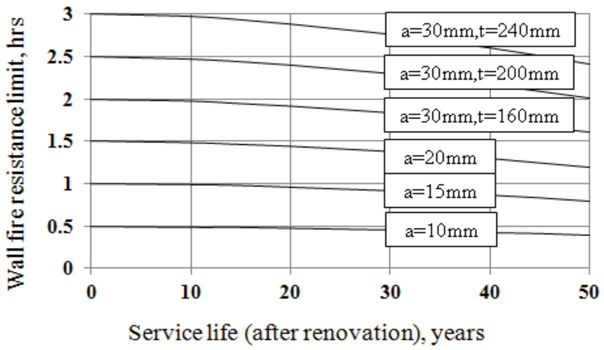

Fig. 3 – Fire resistance limit of reinforced concrete walls of pre-cast residential buildings based on service condition and service life

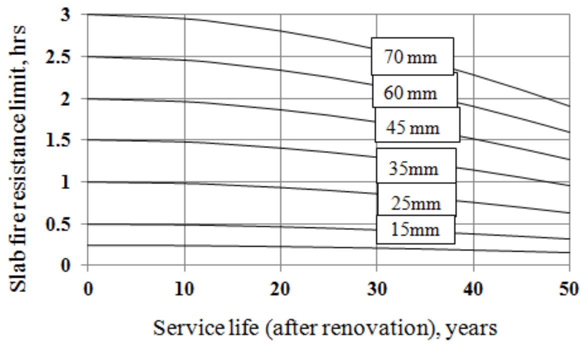

Fig. 4 – Fire resistance limit of reinforced concrete slabs of pre-cast residential buildings based on service condition and service life ($l_y/l_x \geq 1.5$)

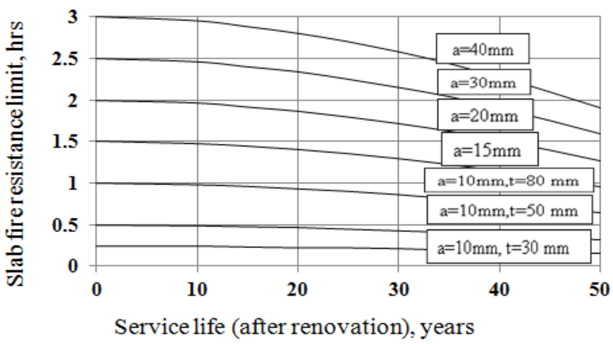

Fig. 5 – Fire resistance limit of reinforced concrete slabs of pre-cast residential buildings based on service condition and service life ($l_y/l_x < 1.5$)

Table 3 – Fire resistance limit of reinforced concrete walls based on service condition and service life

Thickness t_c and concrete cover depth of rebar a, mm		Fire resistance limit, hrs					
		0.5	1	1.5	2	2.5	3
t_c, mm		100	120	140	160	200	240
a, mm		10	15	20	30	30	30
Service life, years	10	0.49	0.99	1.48	1.98	2.47	2.97
	15	0.49	0.98	1.46	1.95	2.44	2.93
	20	0.48	0.96	1.44	1.92	2.40	2.88
	25	0.47	0.94	1.41	1.88	2.35	2.82
	30	0.46	0.92	1.38	1.84	2.30	2.76
	35	0.45	0.89	1.34	1.79	2.24	2.68
	40	0.43	0.87	1.30	1.73	2.17	2.60
	45	0.42	0.84	1.25	1.67	2.09	2.51
	50	0.40	0.80	1.20	1.61	2.01	2.41

Table 4 – Fire resistance limit of reinforced concrete slabs based on service condition and service life (boundary condition, $l_y/l_x \geq 1.5$)

Thickness t_c and concrete cover depth of rebar a, mm		Fire resistance limit, hrs						
		0.25	0.5	1	1.5	2	2.5	3
t_c, mm		30	50	80	100	120	140	155
a, mm		10	15	25	35	45	60	70
Service life, years	10	0.25	0.49	0.98	1.47	1.97	2.46	2.95
	15	0.24	0.48	0.96	1.44	1.92	2.40	2.88
	20	0.23	0.47	0.93	1.40	1.87	2.34	2.80
	25	0.23	0.45	0.90	1.35	1.80	2.25	2.70
	30	0.22	0.43	0.86	1.29	1.72	2.15	2.58
	35	0.20	0.41	0.81	1.22	1.63	2.04	2.44
	40	0.19	0.38	0.76	1.14	1.52	1.90	2.28
	45	0.18	0.35	0.70	1.05	1.40	1.75	2.10
	50	0.16	0.32	0.64	0.95	1.27	1.59	1.91

Table 5 – Fire resistance limit of reinforced concrete slabs based on service condition and service life (boundary condition, $l_y/l_x < 1.5$)

Thickness t_c and concrete cover depth of rebar a, mm		Fire resistance limit, hrs						
		0.25	0.5	1	1.5	2	2.5	3
t_c, mm		30	50	80	100	120	140	155
a, mm		10	10	10	15	20	30	40
Service life, years	10	0.25	0.49	0.98	1.47	1.97	2.46	2.95
	15	0.24	0.48	0.96	1.44	1.92	2.40	2.88
	20	0.23	0.47	0.93	1.40	1.87	2.34	2.80
	25	0.23	0.45	0.90	1.35	1.80	2.25	2.70
	30	0.22	0.43	0.86	1.29	1.72	2.15	2.58
	35	0.20	0.41	0.81	1.22	1.63	2.04	2.44
	40	0.19	0.38	0.76	1.14	1.52	1.90	2.28
	45	0.18	0.35	0.70	1.05	1.40	1.75	2.10
	50	0.16	0.32	0.64	0.95	1.27	1.59	1.91

freeze-thaw action etc. as shown in Eq. (2). In this study, the concrete strength and the rebar corrosion reduction factors are taken in the example calculation.

$$\tau^{s}_{f,r} = \tau^{n}_{f,r} \cdot C_1 \cdot C_{2,1} \cdot C_{2,2} \cdot .. \cdot C_{2n} \quad (2)$$

To determine the reduction factor of the service life C_1, the damage state of structures should be determined first through a detailed inspection of each structure in terms of important characteristics of structure for its technical serviceability such as section dimension, strength, and cracking etc.

A total of 1,077 pre-cast concrete buildings had been built in 1962-1999 in ten districts of Ulaanbaatar. Buildings have 5 to 12 stories with the structural pre-cast reinforced concrete wall and slab panel system without framing. The inspections of more than 60 buildings from these pre-cast concrete buildings in 2001-2015 to assess the structural state of the buildings have been carried out by the authors. The structural deterioration in these buildings was mainly caused by damaged concrete cover, reinforcement corrosion, and multiple freeze-thaw action resulting in the reduced fire resistance. In this paper, test results of 30 buildings located in 10th Micro-district of Ulaanbaatar have been used. From the study, it is observed that external walls, basement floor slabs and walls, and roof slabs are more damaged than the other structural elements due to the reinforcement corrosions. These damage conditions not only deteriorate the load bearing capacity of the structures but also the fire resistance.

The damages of each structural element are registered and a damage degree ω is determined as a ratio of the number of the damaged element to the total number of elements in each structural type. From the data, the correlation between the damage degree ω and the service life of the structure t is observed and the following relations are established through regression equations:

External wall

$$\omega = 0{,}1209 + 0{,}0095t \quad (3)$$

Internal wall

$$\omega = 0.0829 + 0.0019t + 0.00001t^2 \quad (4)$$

Roof slab

$$\omega = 0{,}0862 + 0{,}0032t + 0{,}0001t^2 \quad (5)$$

Floor slab

$$\omega = 0{,}0872 + 0{,}0004t + 0{,}0001t^2 \quad (6)$$

Based on Eq. (4), Eq. (6), and Table 1 and Table 2, the actual reduction of fire resistance of PC slabs and walls can be determined. Results are shown in Figs. 3 through 5 and Tables 3 through 5.

4. Examples of calculation

4.1 Calculation of fire resistance of reinforced concrete slab of 5-story residential building

Data: Basement floor reinforcement concrete slab, 5-story residential building located in the 15th horoolol, Ulaanbaatar. Slab dimension l = 5.4 m; b = 3.6 m; h = 0.12 m. Number of tensile rebars – 18 Class Bp-I, d_s= 5 mm. Concrete class B15, concrete cover depth from the rebar centroid δ = 0.02 m, l_y/l_x = 5.4 / 3.6 =1.5

4-1-a Geometric characteristics required for the calculation

- By load bearing reduction "*R*": $a = \delta + 0.5ds$ = 0.02 + 0.0025 = 0.0225 m
- By insulation capacity "*I*": h = 0.12 m

4-1-b Design fire resistance value for floor slab, 5 story pre-cast panel reinforced concrete building

- By load bearing reduction "*R*", Table 1: if a = 0.015 m then ($\tau^{n}_{f,r}$) = 0.5 hr; if a = 0.025 m then ($\tau^{n}_{f,r}$) = 1.0 hr; a = 0.0225 then ($\tau^{n}_{f,r}$) = 0.875 hr = 52.5 min
- By insulation capacity "*I*", Table 8 [7]: h = 0.12 m, (*I*)= 2 hr = 120 min

4-1-c Actual fire resistance based on service condition and life

- Service life = 34 years
- By load bearing reduction "*R*", Table 3 or Fig 2: if a = 0.015 m then (*R*) = 0.41 hr; if a = 0.025 m then (*R*) = 0.91 hr; if a = 0.0225 m then $\tau^{n}_{f,r}$= 0.785 hr = 47.1 min
- Actual fire resistance based on service condition and life: $\tau^{s}_{f,r}$= 47.1·0.92·0.91 = 39.4 min

It is calculated that the actual fire resistance of the floor slab is reduced by 25 percent based on the service condition and service life.

4.2 Calculation of fire resistance of reinforced concrete wall of 5-story residential building

Data: Reinforcement concrete partition wall, l = 5.4 m; b = *2.8* m; h = 0.14 m. Number of tensile rebars – 18 Class A400, d_s = 12 mm. Concrete class B15, concrete cover depth δ = 0.015 m

4-2-a Wall shall be exposed to the fire from one side. It is very rare for walls to experience fire from both sides. If the wall is exposed to fire from both sides then no deflection takes place and wall still be working under compression [7].

4-2-b Design fire resistance limit of the wall is taken from Table 2.

4-2-c Calculation of geometric characteristics required for the calculation

- By load bearing capacity reduction "*R*": $a = \delta + 0.5d_s = 0.015 + 0.006 = 0.021$ m
- By insulation capacity "*I*": $h = 0.14$ m

4-2-d Calculation of fire resistance of reinforced concrete partition wall, 5-story pre-cast reinforced concrete panel building

- By load bearing capacity reduction "*R*": Table 2 fire resistance limit: if $a = 0.02$ m then $\tau^{n}_{f,r}$= 1.5 hr; if $a = 0.03$ m then $\tau^{n}_{f,r}$= 2.0 hr; if $a = 0.021$ m then $\tau^{n}_{f,r}$ = 1.55 hr = 93 min
- By insulation capacity "*I*": Table.2. if $h = 0.14$ m, then (*I*)= 1.5 hr = 90 min

4-2-e Calculation of the actual fire resistance of reinforced concrete partition wall based on service condition and service life

- Service life = 34 years
- By load bearing capacity reduction "*R*": Table 4 [7] if $a = 0.02$ m then $\tau^{n}_{f,r}$= 1.1 hr; if $a = 0.03$ m then $\tau^{n}_{f,r}$= 1.5 hr; if $a = 0.021$ m then $\tau^{n}_{f,r}$ = 1.14 hr = 68.4 min. Considering reduction of service condition (reduction of concrete strength and rebar corrosion), $\tau^{s}_{f,r}$ = 68.4 ·0.92·0.91 = 57.2 min

It is calculated that the actual fire resistance of the partition wall is reduced by 38 percent from the design value based on the service condition and service life.

5. Conclusions

During renovation and expansion of the existing buildings in use, not only the structural load bearing capacity, and stability requirements but also fire resistance requirements should be considered and satisfied to provide safe living condition to occupants. The Tabulated data method is the most widely used method for practicing engineers today but its application for the calculation of the fire resistance of structures of the existing buildings needs certain modification that accounts the deteriorated state of the structures due to the actual service conditions. From this study, up to 25 to 38 percent reduction in the fire resistance of structures depending on the actual service condition and the service life is observed. Based on the findings of the field study of 30 pre-cast concrete buildings, the empirical regression equations that establish relations between damage degree of structural members and their service life are proposed. Based on these equations, the estimated values of the actual fire resistance limit of PC walls and slabs are suggested in tables and graphical forms that can be used in the calculation of the actual fire resistance of structures of the existing buildings in use for their further renovation. Example calculations are also included.

References

1. Roitman, B.M., (2001) Engineering solution for the assessment of fire resistance in the design of new building and building renovation, Fire Safety and Science Publishing. (*in Russian*)
2. Federor, V.S., Levitskii, V.E., Molchadskii, I.S., and Aleksandrov, A.V., (2004) Fire Resistance and Fire safety of structures, ASV Publishing. (*in Russian*)
3. Lennon, T., Moore, D.B., Wang, Y.C., and Bailey, C.G., (2006) Designers' guide to EN1991-1-2, 1992-1-2, 1993-1-2 and 1994-1-2, Handbook for the fire design of steel, composite and concrete structures to the Eurocodes, Thomas Telford.
4. Beeby, A.W. and Narayanan, R.S., (2005) Designers' Guide to Eurocode 2: Design of concrete structures, Thomas Telford.
5. BS EN 1991-1-2 (2002) Eurocode 1: Actions on structures - Part 1-2: General actions, Actions on structures exposed to fire, British Standards Institution.
6. BS EN 1992-1-2 (2004) Eurocode 2: Design of concrete structures - Part 1-2: General rules, Structures fire design, British Standards Institution.
7. Guideline for the calculation of fire resistance limit of structures, fire distribution limit by structures and material fire ratings, SNiPII-2-80 (1988), TsNIISK imeni V.V. Kucherinko, Stroiizdat Publishing. (*in Russian*)
8. Guideline for the calculation of fire resistance and fire safety of reinforced concrete structure, STO 36554501-006-2006 (2008). (*in Russian*)
9. Rules for fire safety assurance of reinforced concrete structures, STO36554501-006-2006 (2006) FGUP, NITs, Stroitelistvo Publishing. (*in Russian*)
10. Reports submitted to Ulaanbaatar city governor's office: Inspection of Residential Buildings (2014) Mongolian Univ. of Science and Technologies, Ulaanbaatar. (*in Mongolian*)
11. Recommendations for the inspection and assessment of technical state of large panel pre-

cast and masonry buildings (1988) TsNIISK imeni V.V. Kucherinko. (*in Russian*)
12. Duinkherjav, Ya., (2016) The accumulation of defects and damage of concrete structures of existing pre-cast buildings, XIV Concrete Structures Conference, Novosivirsk, Russia. pp.18-22
13. Lennon, T., Rupasinghe, R., Canisius, G., Waleed, N., and Matthews S., (2007) Concrete structures in fire, Performance, design and analysis, Garston, Watford, Bre press.