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Authors(s)	Laefer, Debra F.
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Performance Expectations of Early 20th Century Urban American Building Foundations

Debra Laefer[1], M. ASCE

ABSTRACT: Foundation reuse is a tricky business at the best of times. For structures predating the mid-20th century, the challenge is exacerbated by the presence of a variety of foundation types, techniques, and materials no longer in current usage, such as lime based mortar. Accordingly, the modern engineer is presented with the difficulty of making decisions about assessment and intervention strategies for construction systems, geometries, and methods for which there is no applicable current building code or easily accessible textbook. As foundation reuse, particulary of early 20th century urban buildings, gains in popularity, accessing such information will only gain in criticality. This paper was designed to help amalgamate such information and provide upper limits regarding perfomance expectations of such foundations based on early 1900s' building codes, practices, and testing data, with a typical upperbound of 10MPa in lime.

INTRODUCTION

Foundations, unlike many architectural elements, remain largely undocumented. They are not the subject of coffee table books or extensive scholarly treatises that delve into their origin, development, and geographic distribution. Existing written documentation, sparse at the time of construction, is largely now out of print and generally inaccessible. Furthermore, existing foundations are for all intensive purposes invisible, until critical information about them is needed. This paper is an attempt to begin to rectify this deficit in the literature. For geotechnical engineers, the importance of such knowledge relates mostly to issues of tunneling, adjacent excavation, underpinning, and most recently foundation reuse.

BACKGROUND

Foundation reuse is slowly gaining popularity in the United States (e.g. Strauss et al. 2007, Laefer and Manke 2008). Already a major topic in Europe, drivers related to cost, sustainability risk, and historic preservation are creating additional incentives for foundation reuse within the American market. Figure 1 shows a recent assessment of the current environment, with demarcations closer to

[1] Director of Conservation Research, School of Architecture, Landscape and Civil Engineering, University College Dublin, Phillips Bldg, Room G25, Belfield, Dublin 4, Ireland debra.laefer@ucd.ie

the center of the targets representing stronger drivers than those either unmarked or located towards the outsides of the various target centers.

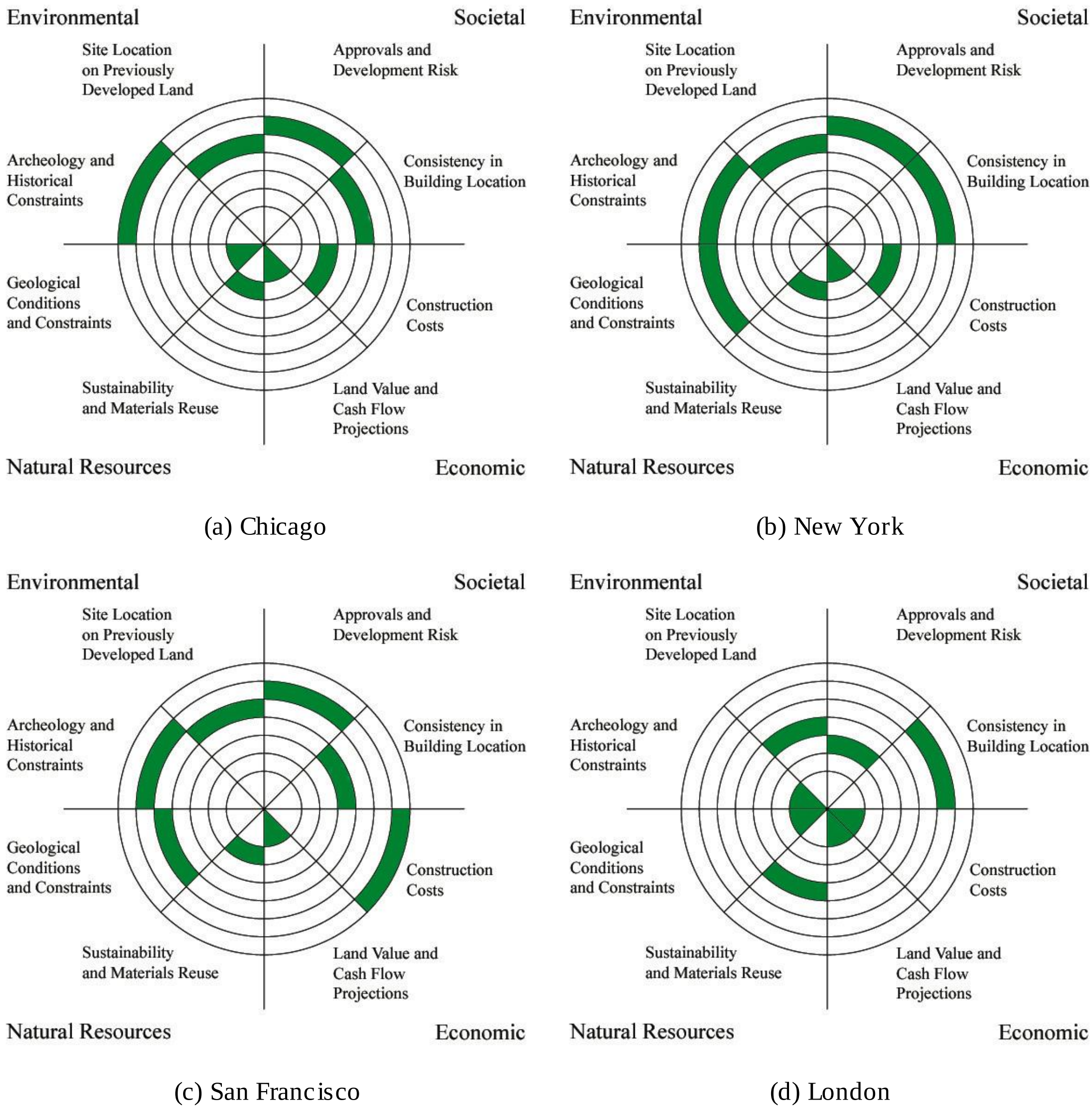


FIG.1. Drivers for foundation reuse (adapted from Strauss et al. 2007).

Foundation reuse may take a variety of forms from simply adding additional load to an existing structure due to a usage change (e.g. from residential to commercial) to the entire removal of the above ground structure with the anticipation of the construction of a larger and heavier structure up above. Before an assessment can be made as to the viability of reusing foundations, or even the development of a testing plan, the engineer must know the foundations' composition, their probable layout, and their initial load capacities. Each of these aspects presents major challenges, especially in light of the fact that original drawings (to say nothing of as-builts) rarely exist. To give an idea of the magnitude of the problem, even in the more regulated area of bridges, the vast majority of their foundations are unknown. According to North Carolina's Department of Transportation, knowledge is lacking as to the type, geometry, and material of the foundations for over half of their more than 13,000 bridges (NCDOT 2003).

CONTRIBUTING FACTORS

An extensive investigation and field-testing program is not cost-effective to determine modern performance possibilities of existing foundations, if the original construction can be shown from the historical record to be inadequate or of highly limited potential. Determining that maximum capacity – (assuming no age-based degradation) is dependent mainly upon three things: (1) the original assumptions about capacity, (2) the foundations' in situ geometry, and (3) the original composite strength of the foundation material.

Original Capacity Assumptions

By the time of Kidder's watershed publication in 1916, American states as far East as New York and as far West as Oregon had in place, if not regulations, then guidelines on allowable loads based on apparent soil type. Although, the categories do not mesh one for one with currently used soil classification systems, strong trends about allowable loads readily emerge (Table 1).

TABLE 1. Allowable loads (kPa) on foundation-beds (data from Kidder 1916).

Character of Foundation-bed	VA	MN	PA	GA	OR	KY	NY	MN	OH	MO	CA
Alluvial soil					48						
Firm dry loam		287		192-287		239	287				287
Soft clay	96	96		96			96	96			96
Ordinary clay								192			
Good solid natural clay										287	
Clay in thick beds, always dry									383		
Clay in thick beds, moderately dry									192		
Firm dry clay	287	287		192-287		239	287				287
Hard clay	383	383		287-383		383	383	383			383
Dry hard clay		335		383							
Ordinary clay & sand together in layers; wet & spring	192	192		192			192				
Moderately dry clay & sand					287						
Stratified clay & stone									383		
Quicksand					48						
Wet sand								96			
Fine sand, firm & dry	287	287		192-287	383	239	287				287
Clean dry fine sand									192		
Dry sand								287			
Coarse compact sand									383		
Firm coarse sand								383			
Very firm coarse sand	383	383		287-383		383	383				383
Stiff gravel	383			287-383		383	383				
Firm gravel		383									
Cemented gravel			575								
Sand loose gravel			335								
Compact sand & gravel									479		
Compact sand & gravel, well cemented									766		
Firm coarse sand & gravel								575			
Gravel & coarse sand, well cemented					766						
Hard-pan							0-1436				
Hard shale, unexposed											1915
Rock					766						1915

These Table 1 values were used in conjunction with allowable loads for certain building types. Although the knowledge of the anticipated load does not specifically preclude significant over-designing, there would need to be additional evidence to justify that the capacity was beyond the anticipated allowable load multiplied by some safety factor.

Typical anticipated live loads were 0.24-0.48 kPa for household and office furniture, 0.48-4.80 kPa for safes, bookcases or filing cases, and 1.20 kPa for dry good stock but which should only be applied to 50% of the floor area (Kidder 1916). Dead load was largely based on the wall width with 55 kg/m attributed to a 0.10m wall, 118 kg/m for a 0.20m wall and 179 kg/m for a 0.31m wall. Kidder further generalized this for 11 cities as a percentage of building loads (Table 2).

Table 2. Footing design loads generalized for 11 cities (after Kidder 1916).

Load	Percentage of Building Load (%)
Live	50
Wind	40
Dead	100

Exactly what the allowable compressive loads are depend upon the specifics of the brick and mortar being used, as well as the city in which it occurred (Table 3). According to other data collected by Kidder (1916), within a certain class or type of brick, the allowable loads were generally a quarter to a third higher for eastern states than western ones, the rationale for which is not given but may be reflective of more modern and, thus, hotter kilns in the East (for more information on kiln development in the U.S. see Laefer et al. 2004). An alternative set of allowable capacities was presented a decade earlier by Mitchell (1904), where stocks is another term for brick. What must be understood with this is that like design today, the allowable loads differed from the ultimate, as discussed in the next section.

Table 3. Comparison of building laws for allowable compressive loads (kPa)

Materials	Boston 1909	Buffalo 1909	Chicago 1914	Denver 1898	New York 1906	Philadelphia 1914	St. Louis 1907
Hard-burned brick in Portland cement mortar	1,915	1,149	2,059	-	1,436	-	2,059
Hard-burned brick in natural cement mortar	1,724	862	958	862	-	1,436	-
Hard-burned brick in cement and lime mortar	1,149	-	-	-	1,101	1,149	1,101
Hard-burned brick in lime mortar	766	575	622	766	766	766	1,053
Pressed brick in Portland cement	-	1,149	-	-	-	-	-
Pressed brick in natural cement	-	862	-	1,149	-	-	-

Table 4. Allowable compressive loads for masonry (Mitchell 1904).

Mortar composition	Proportions	Age (mo.)	Safe load (kPa)
Grey chalk lime : sand	1:2	6	239
Lias lime : sand	1:2	6	478
Lias lime : river ballast	1:6	12	1,436-1,915
Rubble masonry in Lias lime	1:6	12	383
Portland cement : sand (with well burnt stocks)	1:1	3	766
Portland cement : sand (with hard stocks)	1:1	3	958

Original Composite Strength

Lead, natural cements, seashells, and grog (in the form of broken or crushed terra cotta or brick) are just a few of the materials that may be found in historic foundations, but by the early 20th century, at least in urban area, most of the foundations were of brick either dry-laid or set in a lime based mortar or a cement based one. Alternatively natural stone or some type of concrete existed, but by far the most common was brick in a lime or lime/cement mortar. As early as the 1880's there are a variety of tests conducted both small scale and large to try to understand how the various component strengths of the brick and the mortar contribute to the ultimate strength. Additionally, unlike modern concrete. bricks could be and were manufactured with a wide range of resulting capacities.

Presently, figure 2 would be used to depict the relationship between the compressive capabilities of the brick, mortar, and the combined assemblage.

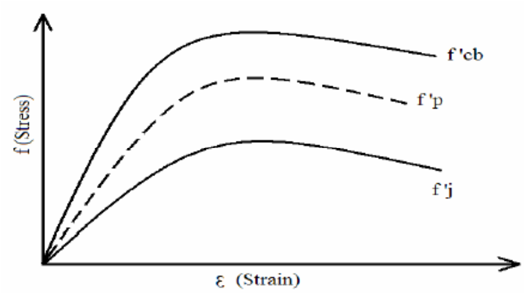


FIG. 2. Comparison of brickwork, brick, and mortar strengths
(after Hilsdorf 1969)

Here, the strength of the mortar is usually substantially less than that of the brick, however, the final masonry strength is considered to be an intermediate value between the two. To calculate this intermediate strength, a brick assemblage is tested, and equation 1 is used to predict strength:

$$f_p' = \frac{\left[f_{cb}' \cdot \left(f_{tb}' + \alpha \cdot f_j' \right) \right]}{\left[U_u \cdot \left(f_{tb}' + \alpha \cdot f_{cb}' \right) \right]} \qquad \text{eqn 1}$$

where f'_p = the composite strength, f'_{cb} = the compressive strength of a masonry unit, f'_{tb} = the tensile strength of a masonry unit, f'_j = the mortar strength, U_u = the non-uniformity factor, and a = j/(4.1*h), where j = mortar thickness and h = masonry unit thickness. The resulting composite strength is a value between the compressive strength of the masonry unit and that of the mortar (fig. 2).

Tables 5-7 provide a sampling of masonry testing that was contemporary with the structures of interest. As described above the mortar and bricks both contribute to the final capacity. Bricks there were more fired as indicated by greater hardness, higher density, and lower absorption are inherently stronger, with those marked as salmons being the least fired of that on the market and of a class usually reserved for non-structural work; additional component data can readily be found in Richardson 1897, Cummings 1897 and Stang et al. 1929.

Table 5. Pier capacity (MPa) as a function of mortar composition (Anon 1907).

	Water struck Rochester, NH Hard	Water struck Rochester, NH Salmon	West Cambridge Hard	West Cambridge Salmon	East Brookfield Hard	East Brookfield Salmon
Neat cement	31.4	12.8	32.4	10.4	13.6	7.3
Cement 1:3	23.6	10.8	12.4	10.5	12.4	8.4
Lime 1:3	6.6	4.5	6.9	5.0-5.6	5.0-6.2	3.2

Table 6. Strength of piers based on brick class and mortar types (Keele 1908).

Brick Manufacturer	Class	Absorption % by weight	Brick crushing (MPa)*	Pier in lime mortar (MPa)^	Pier in cement mortar (MPa)^
Kingston	Best	-	-	-	17.6
	First class	11.9	26.1	3.8	10.5
	Second class	14.9	11.9	-	5.8
	Third class	17.1	12.8	2.0	-
Carlton Clinker	Best	12.7	39.2	4.2	16.6
	First class	16.4	22.0	3.7	15.7
	Second class	-	-	-	7.2
Yorkville	First class	22.7	32.0	3.5	7.3
	Second class	26.7	22.0	2.7	8.1
Humber	First class	12.6	10.0	2.4	-
	Second class	16.7	12.0	2.0	5.6
Don Valley	First class (buff)	9.3	37.0	4.7	7.0
Pressed	Second class (buff)	9.7	24.6	8.4	-

*Two whole bricks tested flat with a thin Portland cement bedding material; lime mortar 1:2 lime:sand mortar f'c=0.5MPa at 2.5 months ^Piers of various heights 8"x8" or 9"x9" in area

Table 7. ASCE 1887-88 Pier Test Data (as reported by Street and Clark 1896)

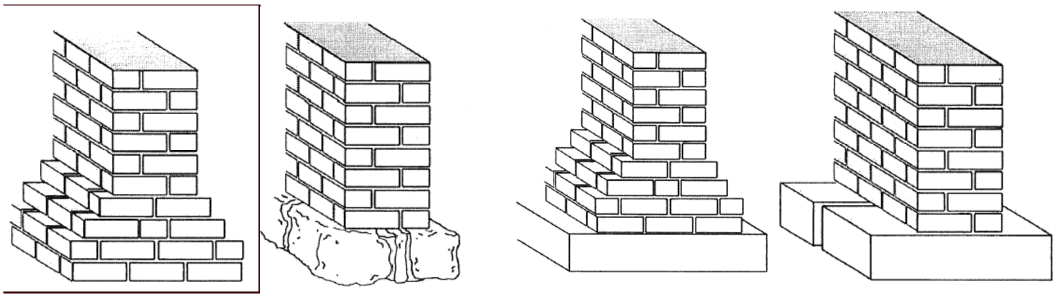
Brick type	Brick f'c (MPa)	Pier f'c (MPa)	Mortar type	Height (m)	Age (mo.)
Common	8.1	11.6	1:2 PC:S	3.1	24.0
Common	8.1	12.3	1:2 PC:S	3.0	24.0
Face	6.1	13.8	1:2 PC:S	3.0	23.5
Face	6.1	13.8	1:2 PC:S	2.0	20.0
Face	6.1	22.4	1:2 PC:S	0.6	18.5
Bay State	5.0	10.0	1:2:6 PC:LM:S	1.9	20.5
Bay State	5.0	12.1	1:2 PC:S	1.8	20.0
Bay State	5.0	11.0	1:2 PC:S	1.8	20.0
Bay State	5.0	8.7	1:2 PC:S	1.9	20.5
Bay State	5.0	14.5	1:2 PC:S	1.8	19.5

PC = Portland cement, S=sand, LM=lime

Molitor published the results of some pier tests that used extremely high strength brick for the period [f'c ranging from 95-134 MPa, where brick up to even an order of magnitude less in compressive strength was not unusual (Molitor 1899)]. Using a variety of mortars with compressive strengths of 0.7-1.4 MPa, most piers tested at 6.9-13.8 MPa depending upon pier height and contributing material.

Foundation Geometry

Traditional foundations can be classified into the modern divide of shallow versus deep. A primary distinguisher of historic foundations from their more modern counterparts is a greater likelihood to be discontinuous. The is true both with respect to a higher reliance on individual pillars and for a lack of continuity along where a modern engineer would expect to see an undisrupted strip footing (FIG. 3). The dimensions of such elements was heavily influenced by local practice and soils, but according to Mitchell (1904) typical widths were 2.4-2.8 times that of the brick wall or pier. Braley (1947) lists this as 2:1, as does Garrett (1948) but as a minimum. As to the wall thicknesses by the second decade of the 20th century these were quite well-regulated for commercial structures (Table 8).



(a) Corbelled brick (b) Ashlars (c) Corbelled brick with continuous concrete slab (d) Uncemented paving stones

FIG. 3. Typical early 20th century foundations.

Table 8. Required wall width per 1916 building codes for commercial structures (data from Kidder 1916).

City	First Floor	Second Floor
New York, Minneapolis, Chicago	31mm	31mm
New Orleans, Denver	33mm	33mm
Boston	41mm	31mm
San Francisco	43mm	33mm
St. Louis	46mm	33mm

Kidder (1916) further reported that the Chicago Building Ordinance for residences, tenements, hotels, and office buildings required 31mm thickness for the basement and first floor walls for 2-story structures (with 20mm for the 2nd floor) and only 31mm and 20mm respectively for the basement and first floor walls for one-story buildings (with or without basement). For all buildings, the cellar and basement wall thickness increased with building height (Table 9).

Table 9. Chicago's required basement/cellar wall thicknesses (after Kidder 1916).

Building Stories	Dwellings, hotels, etc (mm)	Warehouses (mm)
Two	31 or 41	41
Three	41	51
Four	51	61
Five	61	71
Six	71	81

CONCLUSIONS

Conservative assumptions about foundation capacities for early 20th century structures in most of America's major turn-of-the-century cities would lead to the presumption of foundation widths twice the thickness of the ground floor walls made of medium hard brick in a lime mortar resulting in an upper bound of 10MPa, with values of half more typical and those on the west coast less strong than those in the east.

REFERENCES

Anon. (1907). "Strength of Brick and Brick Piers." *Brickbuilder,* 16 (4) 62-65.

Braley, E.L. (1947). *Brickwork: A Comprehensive Treatise on the Theory and Practice of the Handicraft of the Bricklayer,* Pitman & Sons Ltd., London.

Cummings, U. (1897). "Mortar and Concrete: American Cement." *Brick-builder,* 6(1) 11-13.

Garrett, A.J.W. (1948). *Brickwork Including Its Bond, Manufacture and Material Used in Connection Therewith,* Crosby Lockwood and Son Ltd., London.

Hilsdorf, H.K. (1969). "Investigation into the Failure Mechanism of Brick Masonry Products Designing". Johnson F B (Ed.), *Engineering and construction with masonry products.* Gulf Publishing, Houston, TX.

Keele, J. (1908). "Brickwork Masonry." *Applied Science (Incorporated with the Transactions of the University of Toronto Engineering Society),* 2 (2), 69-78.

Kidder, F.E. (1916). *The Architects' and Builders' Pocket-Book,* John Wiley and Sons, Inc., New York.

Laefer, D., Boggs, J., and Cooper, N. (2004). "Engineering Properties of Historic Brick – Variability Considerations as a Function of Kiln Type." *J. American Inst. Conservation of Historic and Artistic Works,* AIC Fall/Winter 43 (3) 255-72.

Laefer, D. and Manke, J. (2008, in press). "Building Reuse Assessment for Sustainable Urban Reconstruction." *J. Construction Eng. and Mgmt,* ASCE.

Mitchell, C.F. and Mitchell, G.A. (1904). *Brickwork and Masonry. A Practical Text Book for Students, and Those Engaged in the Design and Execution of Structures in Brick and Stone,* B.T. Batsford Ltd., London.

Molitor, D. (1899). "The Present status of engineering knowledge respecting masonry construction." *Trans. Assoc. Civil Engineers of Cornell Univ.,* 7, 102-34.

Richardson, C. (1897). "Lime, Hydraulic Cement, Mortar, and Concrete." *Brickbuilder,* 6 (4), 78-79.

Stang, A.H., Parsons, D.E. and McBurney, J.W. (1929). "Compressive Strength of Clay Brick Walls." *Bureau of Standards J. Research,* 3 (108), 507-71.

Strauss, J., Nicholls, R., Chapman, T. and S. Anderson. (2007). "Drivers affecting the frequency of foundation reuse and the relevance to U.S. Cities". Geo-Denver 2007: New Peaks in Geotechnics. Ed. H. W. Olsen, ASCE. *Reston, VA: ASCE,* 0-7844-0897-1.

Street, W.C. and Clark, M. (1896). "Brickwork tests. Report on the first series of experiments." J. Royal Inst. British Architects, 3 (2) April 2, 333-44.