FOUNDATION FAILURES IN NEW RESIDENTIAL CONSTRUCTION

Foundation failures

R. R. MARSHALL
Manager, Halsall Associates Limited, Toronto, Ontario, Canada

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Abstract

The estimated annual cost of claims to warranty programs in Canada from foundation failures is $2,134,000/year. These claims costs do not include owner or builder repairs, or the legal, and administrative costs incurred. Similar soil conditions exist in other countries, so it is likely other geographical locations are experiencing a high cost of failures. These recurring costly failures can be prevented using knowledge we have today. From the survey of 252 major claims, which were confirmed by warranty officials, the most frequent failures were due to adfreezing and swelling clays. These soil conditions caused footings, garage and stairwell components to become unserviceable.

Focusing on appropriate foundation design and proper site analysis could eliminate over 70% of the most costly failures. Building envelope designers specifying good construction practices would help ensure frequent failures are prevented. Technical guidelines have been developed for the most critical foundation elements and system solutions are available.

The bottom line is that it makes economical sense to build foundations rights the 1st time such that major structural and moisture problems can be minimized. These measures need to be implemented by the construction industry. The public should also be protected by better Building Codes and extended warranty coverages.

Keywords: causes, cost, failures, foundation, new construction, residential

1 Introduction

This survey was undertaken on behalf of the Steering Committee for the Development of Performance Guidelines for Basement Envelope Systems and Materials of the National Research Council.

The purpose of the project is to characterize basement envelope failures using statistics provided by New Home Warranty officials in all provinces in Canada. This work adapted the approach for recording construction defects previously developed for the Ontario New Home Warranty Program (ONHWP). The ONHWP data has been extrapolated and presented in this report.

A critical aspect of the work was to attempt to get all the Warranty Program administrators participating in the project so that a national database could be created. A letter of introduction was sent out to all warranty programs. Accordingly, participation by the New Home Warranty Program of British Columbia & Yukon, The Alberta New Home Warranty Program, New Home Warranty Program of Saskatchewan, New Home Warranty Program of Manitoba, Association Provinciale Des Constructeurs D'Habitations du Quebec, and Atlantic New Home Warranty Corporation was achieved.

From the data collected the failures were characterized as follows:

- System type
- Soil type
- Envelope element
- Occurrence
- Severity
- Cause
- Remedial action
- Costs

Patterns were established for the causes for recurring defects in basements. In addition "hot spots" for failures induced by difficult soil or ground water were identified in sufficient detail to allow for specific design and construction recommendations to be made that will reduce problems. The incidence of leakage problems has also been indicated. Builders would adopt good building practice to reduce risk and expensive repairs. Technical guidelines will help the industry utilize the best solutions currently known.

According to Marshall and Martin (1993), foundation failures are the most costly defects in houses in Ontario. The cost in 1992 was estimated at $1.1 million dollars excluding administration costs and costs paid by builders. Finish, plumbing, windows and structural defects were the 2nd to 5th most costly, respectively. Comprehensive research had not been done for other provinces.

2 Methodology and data collection

When one produces a major survey, to characterize the causes of basement failures in new residential construction, the challenge is to assemble it into meaningful and actionable results. The analysis of the survey data helped to highlight 11 key areas of focus. These foundation fundamentals are presented in the conclusions of the report and if implemented will achieve improved quality, and deficient free foundation envelopes.

This survey is the essential first step, which has documented the problems in terms of the most costly and most frequent failures. By prioritizing the failures, the most suitable construction practices can be used to achieve success.

The survey methodology consisted of the following tasks:

- Identification of the number of houses enrolled in each province.
- Establish the frequency and cost of foundation failures.
- Development of a checklist of specific data including construction type, soil type, envelope elements, and cost data.
- A checklist of the characterization of basement envelope failures including detailed technical data on failure mechanism, symptom, foundation component, contributing loads, probable cause and remedial action was developed.
- The survey was conducted with the information gathered from the failure files for 1994 and 1995 from nine Provincial Warranty Programs.

The claims files were confidential and getting access to the data was difficult. It was not possible to send files that contained privileged information across the country for analysis. Due to time limitations, a detailed survey and site visits were precluded. Simplified checklists were developed to expedite the process. In the final analysis, it was necessary to group failure characteristics for similar foundation failure types.

3 Results of survey - Number and cost of failures

Based on available data, 252 structural and environmental failures had occurred in the 9 provinces surveyed. The following is a breakdown of failures reported by province for the 1994 and 1995 period.

Table 1: Failure numbers and costs

Province	**1994**		**1995**	
	Number	Cost	Number	Cost
Newfoundland	15	$44,000	5	$18,000
Nova Scotia	42	$138,360	6	$35,052
Prince Edward Island	2	$19,000	2	$13,000
New Brunswick	27	$221,000	10	$50,000
Quebec	2	$12,476	5	$45,131
Manitoba	6	$29,730	4	$18,500
Saskatchewan	5	$12,000	4	$18,000
Alberta	22	$80,000	10	$30,000
British Columbia	43	$1,222,720	42	$1,194,284
Total	**164**	**$1,779,286**	**88**	**$1,421,967**

The average for the 1994 and 1995 period is 126 failures per year. The failures must be normalized to reflect the annual number of homes enrolled in each province. However, based on the ONHWP geotechnical study, Marshall and Morrison (1995), the total number of failures on average for the 1992 to 1994 period in Ontario was 46 failures/year. This is slightly higher then the second most frequent failures in British Columbia with 42.5 failures/year.

The average cost of structural failures for the 1994 and 1995 period was $1,601,000. Based on failure data from all warranty programs including an estimated annual cost of failures in Ontario of $533,000, the annual cost of foundation failures is about $2,134,000/year. The high cost of failures is unfortunate as we have the knowledge to prevent these failures.

4 Analysis of results

4.1 Analysis by enrolment

A detailed analysis was done of the 1994 and 1995 failures to probe the severity of failures by province and to normalize the data. The number of enrolments is an important factor, as a high failure rate in an area with relatively few enrolments will lead to serious financial problems.

Table 2: Foundation failures ratio by province - 1994 & 1995

Province	Enrolments	Failures	Failure Ratio per 1,000 Enrolments
Newfoundland	1,146	20	17
New Brunswick	2,750	37	13
Nova Scotia	4,294	48	11
PEI	460	4	9
Saskatchewan	1,574	9	6
Manitoba	2,374	10	4
British Columbia	39,549	85	2.1
Alberta	19,644	32	2
Quebec	23,400	7	.3
Total	**95,191**	**252**	**2.6**

One of the main objectives of this survey was to assess claims and to reduce both the incidence and cost of repairs to the participating warranty programs. In Newfoundland 9 of 17 of failures were frost heave related. In New Brunswick 12 of 13 of the failures were caused by adfreezing. 11 of 11 of the foundation failures in Nova Scotia were adfreezing related. Saskatchewan had 3 of 6 of the foundation failures caused by swelling clay.

It is important to understand that the warranty representatives identified adfreezing as the cause of failures and field verification was not possible. Adfreezing occurs when frost susceptible soil adjacent to foundation elements forms a strong freezing bond. Ice lens formation in the soil results in heaving and an upward thrust in the structure.

4.2 Analysis by region

Halifax had the highest number of failures due mostly to adfreezing of basement stairwells.

Table 3: Locations with more than one foundation failure in 1994 – 1995

Location	Average Number of Failure/Year
Halifax (NS)	24
Kamloops (BC)	6
St. John (NB)	3.5
Regina (Sask.)	3
Calgary (Alta.)	2.5
Moncton (NB)	2.5
Gander (Nfld.)	2
Ucluelet (BC)	2
Kelowna (BC)	1.5
Lachenaie (Quebec)	1.5
Quisparisis (NB)	1.5
Saskatoon (Sask.)	1.5

4.3 Analysis by type of foundation envelope system

The data was examined to determine foundation failure occurrences of foundation failure for different types of foundation systems. The most common type of foundation envelope was non-reinforced concrete with 179 of 215 cases. Poured concrete with reinforcing was present in 25 cases and there was 10 block foundation.

A comparison of foundation failure mechanisms and foundation envelope types revealed that for adfreezing type failures, all 10 block foundations representing 100% failure by this mechanism. By comparison, only 1 adfreeze failure occurred with the 25 reinforced concrete foundations representing 4%. According to the data provided by warranty officials, there were 81 adfreezing failures in the 179 non-reinforced concrete foundations representing 45% of the total. The installation of reinforcing seems to have some benefit for reducing the incidence of adfreezing failures.

A further comparison was made of the swelling soil failure mechanism and foundation types. There were 65 swelling soil failures in the 179 non-reinforced concrete foundation envelopes representing 36%. In the 24 reinforced poured concrete foundation envelopes there were 11 swelling soil failures representing 46%.

It is evident that the installation of reinforcing, which consisted mostly of horizontal bars, does little to prevent the foundation envelope failures caused by swelling soils. Swelling pressures can be about as high as 10,000 lbs./sq. ft., which is significantly higher than the 500 lbs./sq. ft. of bearing pressure for typical residential construction. A design approach is required to prevent this type of failure such as preloading the site to consolidate weaker soils in advance of construction.

4.4 Analysis by failure mechanism

Adfreezing cases are the most frequent failure. Adfreezing problems were also the most frequent problem at 48%, according to Marshall and Morrison, (1995). Most cases relate to walkout basement stairwells and unheated garages.

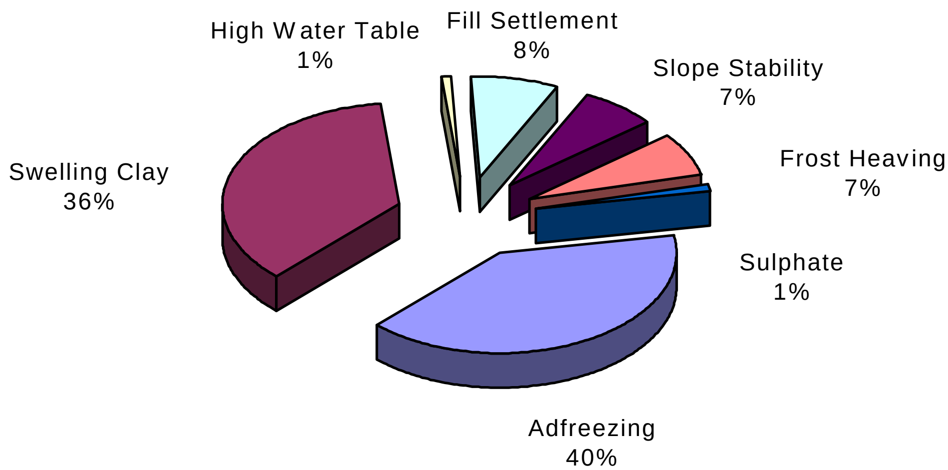

Fig. 1: Overview of failure mechanisms

The two most critical foundation failure mechanisms that must be addressed are adfreezing and swelling clay.

4.5 Analysis by severity

From the data collected it is evident the vast majority of foundation envelope failures result in horizontal and vertical cracks which bow walls, crack drywall, damage doors and impact adversely the operation of windows. A total of 172 of the 215 cases representing 80% fall into this category. The New Home Warranty Programs in Alberta and British Columbia report 13 localized structural collapse failures representing 6% of the failures investigated. No definitive conclusions can be reached from this data as many related symptoms were identified which in combination caused a severe failure. The primary symptom was cracking which would be expected.

4.6 Analysis of failures by components

Walls at 13% and exterior stairwells/steps at 26% and grade beam/slabs at 6 % in total account for 45% of foundation envelope failures. In these cases the failure mechanism is not related to the load bearing characteristics of the underlying soil but the swelling/adhesion characteristics of the surrounding soil which cause the failures.

4.7 Analysis of failures by probable cause

Overall from the data collected it is evident depth of footings is not the most significant probable cause of failure but is a factor often referred to by code users. From anecdotal information from Atlantic NHWP, depth of footing was a factor in 80% of the frost related foundation failures. Design details for frost protected foundations would achieve the most benefits. These should be in the form of guidelines which present the principals mechanisms that must be addressed with adfreezing and the typical practices which have been proven in the field to improve the performance of foundations.

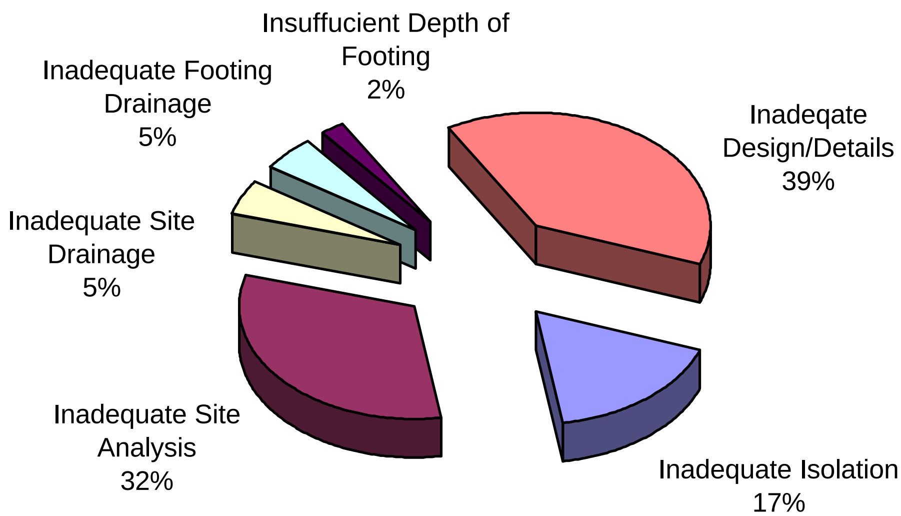

Fig. 2: Probable causes

5 Remedial actions, cost and estimated economic significance

5.1 Action and cost

The most costly remedial actions involved the installation of footing drainage, sumps, and surface drainage work. The total cost of these remedial actions was $1,866,000 for the 71 cases documented. The second most costly remedial action taken was piling under the existing foundation. The total cost of these remedial actions was $620,000 for the 21 reported cases. Interestingly, this remedial approach was undertaken in the two most western provinces with 14 cases in Alberta and 7 in British Columbia. The third most costly remedial actions involved epoxy injection combined with drainage, waterproofing, insulation, drainage layer, footing drainage and surface drainage work. The total cost of these remedial actions was $359,000 for the 72 cases documented. Insulation and footing drainage was the fourth most costly remedial action with a total cost of $92,000 for the 17 failure cases. The fifth and sixth most costly remedial actions were complete system replacement and partial replacement at $84,000 and $66,000 for the 3 and 11 failure cases documented respectively. The seventh most costly remedial action was the installation of a drain layer at $22,000 for the 4 failure cases examined.

It is evident from an evaluation of the remedial measures that in most cases one remedial action could not be undertaken to fix the failed foundation. A systematic approach was necessary in almost all cases to correct the problem. The costs per remedial case were very expensive. For example in the top 2 categories, the per failure unit cost for the footing drainage, sump system and surface drainage was $26,000/case and per failure unit cost for piling was $29,000. If the foundations were built right the first time, it is estimated the added construction cost would have been only $5,000 to $7,000 which is less than 25% of the remedial cost.

5.2 Estimated economic impact

It is essential that any measures that are implemented to prevent foundation failures be done in a cost effective context. This survey documented the cost and frequency of failures and has not examined the costs of preventing the problems. However, if investments are to be made to address these failures we need to know at least notionaly that the economic returns in the form of lower repair costs and warranty rates will be much greater than the costs of new procedures and training initiatives. A balanced and targeted approach will work best where builder information is key and the focus of education is matched to the areas with the highest risk.

A national assessment of the economic impact of various action plans was completed. Based on 100,000 new homes constructed a year, and a mandated certification inspection program for the design and field review of all foundations, the estimated cost for engineering would be $85,000,000/year or $850 per lot. (A range of fees from $200 to $1500 has been assumed). Clearly, it is not a good investment to spend $85 million to save $2 million.

What is required is a balanced preventative approach. Thus, assuming an estimated 20,000 registered builders had the failure information in this report and were provided with practical guidelines to prevent foundation envelope failures, at a cost of $10/builder, the estimated cost to new home buyers would be $200,000. This is less than 10% of the annual cost of failures. If only 50% of the failures were prevented, over $1,000,000/year in repair costs would be saved.

By combining this technical information, with a targeted educational program in the foundation failure “hot spots”, builders could better manage their risks without adding to the cost of construction in all locations. Builders would also achieve an enhanced reputation and at the same time provide to their customers a better built and deficient free home.

Warranty programs should be instrumental in affecting the behavior of builders who choose to ignore the foundation failure prevention guidelines. Assuming focused hands-on workshops were held in conjunction with Home Builder local and/or Building Official chapter meetings, the cost for workshops would be minimal. The only cost other than out of pocket expenses would be for the creation of customized regional workshop modules for swelling clay and adfreezing. It would not be effective to speak on swelling soil in Halifax when adfreezing is the most important foundation failure mechanism.

6 Discussion and conclusions

- A total of 252 claims have been surveyed from 9 provinces. This provides a valid sample to characterize the causes of foundation envelope failures.
- The cost of failures of $3,201,000 or $13,000/failure is significant. The total cost could be much higher if the costs of administration, engineering and repair costs paid by builders, consumers and municipalities were also included.
- A total of 172 of the 215 cases representing 80% of foundation envelope failures result in horizontal and vertical cracks which bow walls, crack drywall, damage doors and adversely affect the operation of windows. Home owners need protection for these performance problems. Consumers especially in the Atlantic Provinces, Saskatchewan and Manitoba who have high foundation failure ratios are at the greatest risk.
- NRC through industry partners should create good practice technical guidelines, which reflect regional problems. These can be used to prevent the most common and costly problems. The guidelines and other useful resources should be referred to in the Code Appendix, Housing Illustrated Guides and the Part 9 Commentary.
- The estimated economic impact indicates it would be beneficial to invest in information dissemination and educational programs to assist builders in preventing foundation failures. This would help reduce warranty repair costs and provide Canadians with more deficient free foundations.
- Foundation failure rates in Newfoundland, New Brunswick, Nova Scotia, Prince Edward Island, Saskatchewan and Manitoba are above average in terms of claim to enrolment ratios for the 1994 and 1995 years. The leading failure mechanisms are adfreezing and swelling clay. The high cost of swelling clay, hillside slippage and collapsible soil foundation failures in British Columbia must be covered.
- It would be economical to do site analysis and incorporate better design practices for foundations built in the regional areas of Halifax, Kamloops, St. John, Regina, Calgary, Moncton, Gander, Ucluelet, Kelowna, Lachenaie, Quisparisis and Saskatoon. It would be prudent for builder/developers to ensure soils information is obtained prior to the construction of the foundations. By engaging a competent geotechnical consultant, the risk to the builder of foundation failures is drastically reduced. At the inspection stage, municipal and private inspectors should be focusing their efforts on checking for poor soils.
- It is essential improved practice methods be further refined to prevent adfreezing and better practices be identified for swelling soil foundation envelope failures. These practices must be widely distributed in all areas where these failures are known to occur directly to all builders and through local jurisdictions.
- No other reports are available to indicate whether the frequency of foundation failures is on the rise or is decreasing. Once the solutions are implemented, it is essential to measure the results. An analysis of claims should be conducted within three years to assess the impact of the measures implemented.
- The collection methodology was successful as we learned vital information from each occurrence of envelope foundation failure. This is essential to prevent future recurring defects. The checklist approach is excellent but should be shortened to two pages to help simplify their completion by technical personal. From a risk

management perspective, only failures with higher cost and high rates of frequency should be analyzed in detail. Consideration should be given to site verification of a sample of the failures.

- To ensure the most practical solutions are developed in the technical guideline, an important next step in the process is to assemble key people in a facilitated expert's forum. The face to face exchange of information would be a learning experience for all participants. The practical solutions that are identified for the most common and costly foundation failures must be incorporated into the final performance guideline.

7 Recommendations

The results of this survey clearly indicate that there are significant opportunities to improve the performance of foundation envelope systems. The recommendations, which are presented below, focus on improving the process of foundation construction.

- The most serious foundation failures from metastable soils and swelling clays are occurring in British Columbia and western provinces. The high foundation failure ratios for the Atlantic Provinces and Saskatchewan are somewhat alarming. Prevention methods for swelling clays, adfreezing, settlement, slope stability and frost heaving foundation envelope failures must be established. The leadership role of the National Research Council of Canada should be maintained to identify design principals and best available alternatives.
- Details are the key if foundation failures are to be prevented. Performance Guidelines created by NRC will be used by designers to address foundation failures. The practicality of construction must also be reflected if the details are to be adapted for use on project drawings and implemented in the field. Therefore, it is recommended that the Performance Guidelines be developed in partnership with leading builders that have experience in building in problematic areas. The guidelines must have a high degree of illustrated content to ensure users understand good engineering practice.
- Site analysis is essential. A thorough and complete geotechnical investigation must be conducted and the designer recommendations followed. The analysis will allow for the specific details to be identified by the designer for each individual building. The specific materials and components would be specified for an appropriate foundation envelope system, which meets the site conditions. It is recommended that site analysis be done in all areas where frequent foundation envelope failures are known to occur.
- An educational program organized through local Home Builders Association locals and chapters of the Building Officials Associations should be delivered in the areas where the highest rates of failure are occurring. Short seminars could be presented at builder/building official/private inspector regular scheduled meetings and hands on workshops should be held with builder/inspector/professional trainer teams to facilitate the learning of new procedures which will prevent foundation envelope failures.
- The structural performance of foundations is an important fundamental purpose of Building Codes. To ensure all Code users are aware of the performance guidelines that are developed, it is recommended the guidelines be referenced in the Appendix of the Code and supporting documents. Furthermore, it is recommended that Warranty

Programs make this information available to their registered builders at a discounted rate to reduce their risks of future payouts.

- To ensure the frequency and cost of foundation failures is reduced; it is recommended a survey of failures be undertaken within three years to assess the various measures, which have been implemented. The same successful survey methodology should be used. A revised checklist to characterize foundation failures should be developed and disseminated to interested parties.
- The cost of foundation failures is high and with increasing development on marginal lands and infill sites, it is expected problems will continue unless research is undertaken to develop superior and simpler approaches to foundation design and construction. There is a need for further research and guidance on isolation methods, which eliminate the characteristics of poor soils, and superior foundation systems, which are more resistant to frost damage.

8 References

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