URBAN SOILS

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Keywords: Anthropogenic soils, corrosion, erosion, floods, pollution, soil classification, urban soils, urban land use, wetlands.

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Summary

Urban and industrial land uses are particular land uses, making great demands on soils for filtering toxic pollutants or providing firm foundations for buildings and larger structures. Urban and industrial planning should be based on detailed soil surveys in order to evaluate how well soils at a site are suited for the required functions. Failure to do so can lead to expensive failures.

Some soils have serious limitations for certain urban land uses. Construction on such soils should be avoided or special (often expensive) techniques be used to overcome these. Problem soils for buildings, roads, underground pipelines, etc. include, *inter alia*, swelling clay soils, water-saturated soils and corrosive soils. Sandy soils, especially light gray sands, are unsuitable for the disposal of toxic effluents, since they lack the capacity to retain pollutants.

Urban land uses also cause dramatic changes to some soil properties and characteristics, leading to strong layering and a decrease of pH values. As a result, plant-availability

and mobility of toxic heavy metals in soils are increased, leading to human health and environmental hazards. Soil erosion in urban areas, especially from construction sites, is worse than from farmland. Overall, the loss of soil quality and the increasing invasion of good farmland by urban development has become a matter of concern, especially in countries with limited good cropland and where it can threaten national food security.

Special classification systems have been developed for soils affected by urban and industrial land uses. Mapping of urban soils is difficult because they do not have definite patterns associated with climate, parent material or topography.

1. Introduction

Worldwide large areas of land are occupied by expanding cities. About half of the world's population is presently living in urban and peri-urban areas. For industrialized countries the figure is about three quarters. The expansion of urban areas increases continuously, even in countries that have been industrialized for a long time. In the USA alone 1.4 million acres (560 thousand hectares) of land were converted to urban areas *per year* during the period 1982-1992. This increased to an annual 2.2 million acres (880 thousand hectares) during the period 1992-1997, i.e. an increase by nearly 60%. This means that just in the USA 10 million hectares of land were invaded by new urban areas during this 15 year period. Urban areas expand into surrounding cropland, rangeland and forests. Even in the USA, a country very richly endowed with high quality cropland, there is concern about the alarming rate at which prime farmland is vanishing due to urban expansion in some regions.

Urban development is a rather particular type of land use. Soils are subjected to major physical changes, especially during construction activities, or receive very high loads of waste materials per unit area. Soils have to cope with addition of these materials, including solid wastes, sewage sludge, chemical pollutants, etc. and are therefore required to act as filters to clean these up so that they do not enter the wider environment.

It is important to use appropriate criteria for evaluating the suitability of soils for different urban land uses, e.g. as foundation materials for houses, disposal sites, etc. Knowledge of the suitability and constraints of different soils for various urban land uses will permit selecting appropriate sites and technologies for developments that at the same time will be economical and safe for individuals, society and ecosystems. Failure to take soil characteristics and qualities into consideration during urban planning and development can lead to expensive maintenance costs afterwards, and even to disasters.

Urban activities create different types of new man-made soils that differ widely from natural soils, and special soil classification systems have been developed for the classification of these real "urban soils". In most modern comprehensive soil classification systems special classes have also been developed for anthropogenic soils. Anthropogenic soils are soils that have developed under strong influence of human activities and include urban soils.

In a more general sense, however, all soils found within an urban environment can be considered urban soils, including the relatively undisturbed natural soils of forests and other natural conservation or recreational areas, such as picnic areas, found within urban boundaries. It would also include agricultural land found within peri-urban areas.

The information used in this paper was either extracted from the publications listed under "Bibliography" at the end of the paper or was based on the author's personal experience.

2. Suitability of Soils for Urban Development

A suitability evaluation of soils for different urban land uses is basically not different from a similar exercise for any other land utilization type (LUT). For each urban LUT the following is needed before development planning can be done:

a) Soil requirements and soil tolerances of each LUT must be determined. Requirements refer to ideal conditions for a specific LUT, and tolerances indicate maximum deviations from the ideal that can be permitted before the soil becomes unsuitable for that LUT.
b) Properties, characteristics of different soils and resultant qualities for different urban LUT's must be determined.
c) Matching of soil requirements and tolerances of each LUT with the qualities of the different soils of the area earmarked for development must be done to determine which areas are suitable for which LUT's.

A prerequisite for successful development planning is that detailed soil maps, based on high quality intensive soil surveys, must be used during the planning process. To ensure that all relevant soil information is recorded during the soil survey, the surveyors must establish before the start of the survey, soil tolerances and requirements for the different LUT's, in consultation with specialists in engineering, town planning, architecture, landscape architecture, etc.

Similar soils tend to behave similarly in response to specific uses. Knowing how a specific type of soil behaved under a specific use elsewhere thus enables planners to predict the soil reaction under the same land use in the area of planning. The process of developing a plan on known experience under similar conditions elsewhere is called technology transfer. In order to be sure that one is dealing with similar soils requires the use of a good well-structured soil classification system.

The urban scene includes a wide range of different LUT's, for each of which a separate suitability evaluation must be done. In the USA detailed soil survey reports for counties display tables giving ratings of the limitations of different soils for town and regional planning. These include for each soil mapping unit a suitability rating (slight, moderate or severe constraints) for (1) dwellings with basements; (2) shopping centers and small industrial buildings; (3) local roads and streets; (4) septic tank absorption fields; (5) underground public utilities; (6) sanitary landfill (trenches); (7) lawns, landscaping and golf fairways; (8) picnic and play grounds; (9) camp areas; (10) paths and trails; and (11) athletic fields. Furthermore, they rate different soils as poor, fair or good as sources for topsoil, sand and gravel or fill material respectively.

In view of the major impacts of different types of soils on the various urban LUT's it is amazing how often urban planning is done without consulting appropriate soil maps and information, often with grave consequences for individuals and urban societies. In many cases when this happens, city administrators state that it could not be foreseen. The truth is that if they did proper land suitability evaluations, based upon appropriate soil surveys, the problems could have been foreseen and thus could have been avoided or mitigated.

Only three of the most serious and most widely found soil problems in urban planning are briefly discussed below, but there are many more. The discussions concentrate on effects on buildings and underground structures like pipelines. Effects on roads, sports fields, picnic areas, etc. are not discussed here but are equally important. More information on these can be found in Craul (1999).

2.1. Swelling Clay Soils

Swelling clay soils, i.e. soils with a large swell-shrink potential, are a serious problem in urban development. Although these soils cover only a relatively small proportion of the total land area of the world, they underlie an amazingly large proportion of urban areas. This is probably related to the fact that most urban areas are found on plains or on gently sloping foot slopes in lower landscape positions. Muckel (2004) estimates that in the USA, a country with only a low percentage of swelling clay soils, about half of the homes are built on such soils; apparently, they cause more damage to homes each year than floods, tornadoes and hurricanes together.

The outstanding characteristic of swelling clays is their big volume and internal pressure changes during alternate wetting and drying. During wetting they absorb a large amount of water and swell; during drying they lose this water and shrink. When such soil shrinks, large cracks, wide and deep, are formed, and tremendous forces equivalent to several tons per square centimeter develop. These forces are extremely destructive to buildings, roads, airport runways, storm water deviation canals, etc. as well as to underground structures like pipelines.

The effects of this alternate swell-shrink process are particularly severe in areas with distinct alternate rainy and dry seasons, especially in hot sub-humid to semiarid regions. Surface layers dry out faster than deeper horizons, and this leads to uneven shrinking rates between the various soil layers, and in tension differences acting on structures and underground installations.

Lateral differences in soil water content, i.e. where some spots dry out faster than others, also introduce additional forces. Slickensides, i.e. polished, grooved friction planes, in swelling clay soils reveal the degree to which different sections of such soils slide over each other due to differential wetting and drying.

In the case of buildings erected on such land, the cracks that develop in the soil extend through the foundations of the buildings and from there right through the walls (Photo

1). In the case of multi-storey buildings, cracking of walls is not confined to the ground floor only, but extends into upper storeys as well. Cracking of walls is aggravated by unequal soil movements caused by bigger and faster changes in soil water content near the edges of the structure than elsewhere under it. An example of this effect is the serious cracking of houses near corners where gutter pipes deliver large amounts of water to the soil during rains.

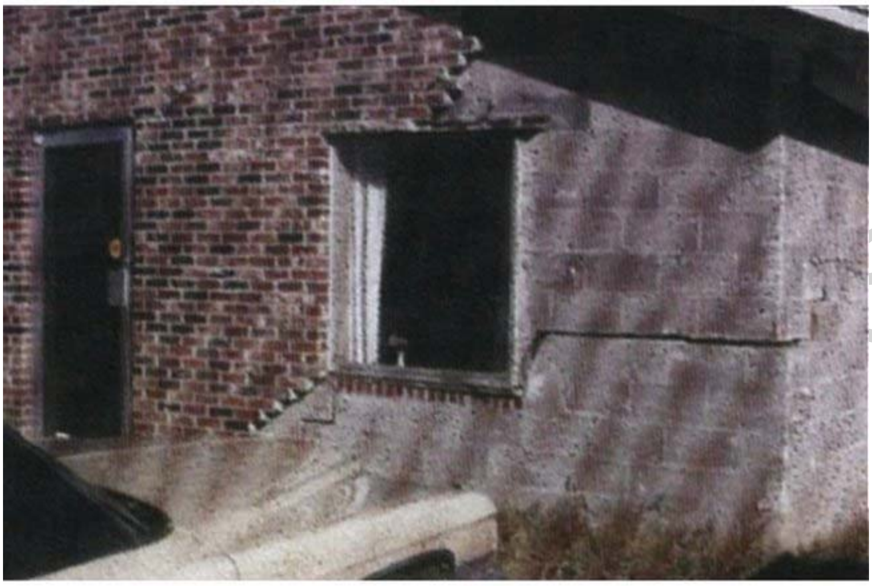

Photo 1: Cracking of a house on swelling clay soil (Source: Muckel, 2004).

Cracking of a building on swelling clay soil is not once-off, but continuously recurring after each wet-dry cycle. Thus, a continuous expensive reparation of cracks is required. In some cases the structural strength of the building deteriorates so much over time due to repeated cracking that it leads to safety hazards and demolition of the building. Uneven swelling and shrinking of soils under buildings also leads to warping of door sills, posts and window frames to such an extent that the doors and windows can eventually no longer open or close. (See warping of window frame in Photo 1.)

The best way to overcome hazards of swelling clay soils is to avoid building on them, by identifying their localization with the use of soil maps beforehand. Where building on swelling clay soils is unavoidable, several techniques can be used to mitigate the effects of the swell-shrink process. In the case of single-storey buildings an effective technique is to construct the building on a reinforced concrete slab that will "float" on the soil surface, instead of using conventional foundations sunk into the soil. Floating of the slab can be enhanced by putting it on a layer of gravel or coarse sand. Unfortunately the building regulations of municipalities or city councils usually do not allow for the use of such floating slab foundations.

Another relatively expensive construction technique for application on swelling clay soils is the use of piles. These are vertical pillars, often made from steel reinforced concrete and sunk into the ground through the total depth of the swelling clay, so that they rest on the stable material below. In soils with extreme swell-shrink properties conventional piles often do not work. The author knows of an example where one corner of a house built on reinforced concrete piles cracked off from the rest of the house. Excavation afterwards revealed that the steel reinforced pile at that corner had snapped due to differential pressures at the transition between the dried out topsoil and the wet lower part of that soil.

2.2. Water-saturated Soils

Water-saturated soils are soils that have a water table (free water standing in the soil) near the surface, which can be permanent or fluctuating. A water table has a negative effect when its upper boundary is within the depth of construction (or within the normal rooting depth of plants). Such areas often correspond to wetlands.

Waterlogged soils have various limitations for use as building sites and, therefore, cause several problems. First, the soil cannot be compacted to provide a firm foundation for buildings, pavements or roads. Moreover, under excessively wet conditions slumping is common, resulting in foundation failures. When the level of a water table drops due to either a prolonged drought or to groundwater exploitation for drinking water purposes, the hydrostatic pressure is reduced and the soil subsides, leading to structural failures or other problems in buildings.

Photo 2: Structural damage due to subsidence of a waterlogged soil (Source: Laker).

A good example of the above is found in the city of Bangkok, Thailand, where underground water is exploited for water supply to the city. In some cases the subsidence of the soil in Bangkok has required the construction of two or more additional steps to get into major buildings. Piles, put through the waterlogged zone onto firm material, can be used to give firmer foundations. During subsidence of the soil, the lower parts of walls can drop down between the piles, leaving huge horizontal gaps between the part that has dropped out and the upper part still "hanging" between the piles. The author saw a striking example of this in a building at a university campus in Bangkok (Photo 2).

Houses built on wet soils are subject to problems of dampness of walls and cupboards, and of damage to floor carpets, etc. Basements are highly prone to wetness. High water tables create moreover a poor functioning of septic tanks.

Flooding is common in wetland areas and can cause major disasters. Flood hazards can be diminished by constructing cut-off drains above the wetland areas to prevent water flowing from higher slopes. The areas themselves can also be drained, though such artificial manipulations of the water may cause various additional problems.

Building of houses in or near wetlands can have serious health risks for humans, for example in areas where malaria is prevalent.

Apart from the problems related to urban development in wetlands, there might also be other important reasons, mainly of an environmental or ecological nature, for prohibiting the development of such areas, as will be discussed later.

2.3 Corrosive Soils

Some soils cause serious corrosion of various metals or concrete, which are extensively used in urban development for underground facilities, foundation materials, etc. Buildings, streets and sidewalks (due to damage to their foundations), pipelines for gas, sewage and water and fuel (petrol, diesel) storage tanks under filling stations are most vulnerable to the effects of corrosion damage.

Where unsuitable materials or inadequate protection are used in corrosive soils, expensive continuous maintenance may be required. Damage caused by corrosive soils is usually only visible underground, and therefore it is often not noticed before it is too late. Water leaking from corroded pipes will not only raise the water account of a home owner sky high, but may lead to localized water-saturated areas that cause slumping of foundations and structural damage to the house. The author once found that the problems experienced by a farmer in his citrus and subtropical fruit orchard was caused by the fact that the borehole which he used for irrigation was heavily polluted with diesel. The source of the diesel could be traced to a leaking diesel storage tank, due to corrosion, under a nearby fuel filling station.

Saline soils, i.e. soils with high soluble salt contents, cause serious corrosion of metal structures, e.g. water or gas pipes. Saline soils are relatively abundant in arid areas and in low landscape positions in semiarid areas. When urban development takes place on such soils water is supplied for domestic use, gardening, creation of parks, golf courses, etc. The increased wetness of the salt-bearing soils then "triggers" their corrosive action. In coastal areas salt spray, blown in by wind from the sea, increases soil salinity. In desert areas with large, dry playas (salt plains) fine salt dust is distributed by wind, often over appreciable distances, thus increasing the salinity of surrounding soils.

At the other extreme, strongly acid soils are very corrosive to concrete. Cement, a material with basic reaction, is a main constituent of concrete. A simple base-acid neutralization reaction occurs between the concrete and the acid. Associated acid-forming salts will also corrode metal structures, such as pipes. Strongly acid soil conditions are mainly found in high rainfall areas. The worst soils in this regard are the so-called “acid-sulfate” soils. These are soils that contain iron sulfides, which are oxidized to sulfuric acid when exposed to oxygen due to drainage, dredging or excavation of the soil.

Similar situations occur when urban development is carried out on former open-cast or strip coal mining terrains. Some sulfide containing coal dust or fragments inevitably remains behind in the reclaimed soil.

3. Effects of Urban Land Use on Soils

Urban land use and related activities may have drastic effects on soils and change the physical and chemical properties of the profile. The end result is a soil that differs completely from the original. The effects of urban land use on soils is much greater than the effects of rural uses, like agriculture or forestry. This is due to both the much more aggressive impact of urban land use and its much higher intensity.

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Biographical Sketch

Michiel Laker is Emeritus-Professor of Soil Science, University of Pretoria, South Africa. He holds a DScAgric in Soil Science (1971) from the University of the Orange Free State, South Africa. He is a former president of the Soil Science Society of South Africa and of the Southern African Association for Farming Systems Research-Extension. He is a member of the Soil Classification Working Group of South Africa and a former member of the WRB Working Group of the IUSS, to which he still contributes, and the Soil Degradation and Desertification Working Group of the IUSS.

He lectured in soil science for 35 years, giving various courses in soil fertility, soil chemistry, soil physics, pedology and land use planning, as well as special soil science courses for students in landscape architecture and wildlife management. He supervised post-graduate students in various fields, mainly in soil compaction, soil erosion, irrigation and land use planning. Since retirement he is consultant in soil science, land use planning and agricultural development, focusing mainly on irrigation development small-scale farming.