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ORIGINAL ARTICLE

Environmental problems caused by Istanbul subway excavation and suggestions for remediation

Ibrahim Ocak

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Abstract Many environmental problems caused by subway excavations have inevitably become an important point in city life. These problems can be categorized as transporting and stocking of excavated material, traffic jams, noise, vibrations, piles of dust mud and lack of supplies. Although these problems cause many difficulties, the most pressing for a big city like Istanbul is excavation, since other listed difficulties result from it. Moreover, these problems are environmentally and regionally restricted to the period over which construction projects are underway and disappear when construction is finished. Currently, in Istanbul, there are nine subway construction projects in operation, covering approximately 73 km in length; over 200 km to be constructed in the near future. The amount of material excavated from ongoing construction projects covers approximately 12 million m^3. In this study, problems—primarily, the problem with excavation waste (EW)—caused by subway excavation are analyzed and suggestions for remediation are offered.

Keywords Environmental problems · Subway excavation · Waste management · Excavation waste

I. Ocak
Rail Transport Construction Department,
Istanbul Metropolitan Municipality,
IETT General Directorate, Karaköy-Istanbul, Turkey

I. Ocak (✉)
Mining Engineering Department, Istanbul University,
Avcılar-Istanbul, Turkey
e-mail: iocak@iett.gov.tr

Introduction

Nowadays, cities are spreading over larger areas with increasing demand on extending transport facilities. Thus, all over the world, especially in cities where the population exceeds 300,000–400,000 people, railway-based means of transportation is being accepted as the ultimate solution. Therefore, large investments in subway and light rail construction are required. The construction of stated systems requires surface excavations, cut and cover tunnel excavations, bored tunnel excavations, redirection of infrastructures and tunnel construction projects. These elements disturb the environment and affect everyday life of citizens in terms of running water, natural gas, sewer systems and telephone lines.

One reason why metro excavations affect the environment is the huge amount of excavated material produced. Moreover, a large amount of this excavated material is composed of muddy and bentonite material. Storing excavated material then becomes crucial. A considerable amount of pressure has been placed on officials to store and recycle any kind of excavated material. Waste management has become a branch of study by itself. Many studies have been carried out on the destruction, recycling and storing of solid, (Vlachos 1975; Huang et al. 2001; Winkler 2005; Huang et al. 2006; Khan et al. 1987; Boadi and Kuitunen 2003; Staudt and Schroll 1999; Wang 2001; Okuda and Thomson 2007; Yang and Innes 2007), organic (Edwards et al. 1998, Jackson 2006; Debra et al. 1991; Akhtar and Mahmood 1996; Bruun et al. 2006; Minh et al. 2006), plastic (Idris et al. 2004; Karani and Stan Jewasikiewitz 2007; Ali et al. 2004; Nishino et al. 2003; Vasile et al. 2006; Kato et al. 2003; Kasakura et al. 1999; Hayashi et al. 2000), toxic (Rodgers et al. 1996; Bell and Wilson 1988; Chen et al. 1997; Sullivan and Yelton 1988), oily

(Ahumada et al. 2004; Al-Masri and Suman 2003), farming (Garnier et al. 1998; Mohanty 2001) and radioactive materials (Rocco and Zucchetti 1997; Walker et al. 2001; Adamov et al. 1992; Krinitsyn et al. 2003).

Today, traditional materials, including sand, stone, gravel, cement, brick and tiles are being used as major building components in the construction sector. All of these materials have been produced from existing natural resources and may have intrinsic distinctions that damage the environment due to their continuous exploitation. In addition, the cost of construction materials is incrementally increasing. In Turkey, the prices of construction materials have increased over the last few years (Fig. 1). Therefore, it is very important to use excavation and demolition wastes (DW) in construction operations to limit the environmental impact and excessive increase of raw material prices. Recycling ratios for excavation waste (EW) and DW of some countries are in shown Table 1 (Hendriks and Pietersen 2000). The recycling ratio for Turkey is <10%.

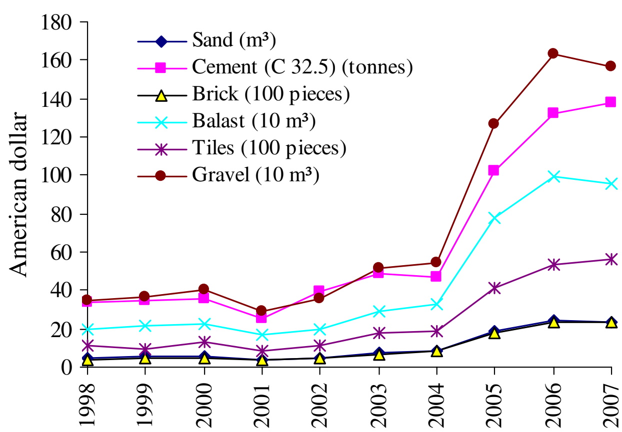

Fig. 1 The increase of construction material prices over the last 10 years

Every year, 14 million tons of waste materials are generated in Istanbul. These waste materials consist of 7.6 million tons EW, 1.6 million tons organic materials and 2.7 million tons DW (IMM 2007). The distribution of waste materials, according to listed sources, can be seen in Figs. 2 and 3. Approximately, 3.7 million tons of municipal wastes are produced in Istanbul every year. However, the recycling rate is approximately equal to only 7%. This rate will increase to 27%, when the construction of the plant is completed. Medical wastes are another problem, with over 9,000 tons dumped every year. Medical wastes are disposed by burning. Distributions of municipal wastes are given in Fig. 4.

In this study, environmental problems in Istanbul, such as EW resulting from tunnelling operations, DW resulting from building demolition and home wastes, are evaluated. Resources of EW, material properties and alternatives of possible usage are also evaluated.

Railway system studies

Three preliminary studies concerning transportation in Istanbul were conducted in 1985, 1987 and 1997. A fourth study is currently being conducted. The Istanbul Transportation Main Plan states that railway systems must constitute the main facet of Istanbul's transportation network (IMM 2005). In addition to existing lines, within the scope of the Marmaray Project, 36 km of metro, 96 km of light rail, and 7 km of tram, with a total of 205 km of new railway lines, must be constructed. Consequently, the total length of railway line will exceed 250 km.

Table 1 Comparison of a few countries' construction waste concentration

Country	Concentration of CW in total waste (in %)	CW and DW recycled (in %)	Source
Denmark	25–50	80	Hendriks and Pietersen (2000)
Netherlands	26	75	Hendriks and Pietersen (2000)
Japan	36	65	CMRA (2005), Hendriks and Pietersen (2000)
Australia	44	51	Hendriks and Pietersen (2000)
Germany	19	50	CMRA (2005), Hendriks and Pietersen (2000)
Finland	14	40	CMRA (2005), Hendriks and Pietersen (2000)
United Kingdom	over 50	40	Hendriks and Pietersen (2000)
USA	29	25	CMRA (2005); Hendriks and Pietersen (2000)
France	25	25	CMRA (2005); Hendriks and Pietersen (2000)
Spain	70	17	Hendriks and Pietersen (2000)
Italy	30	10	CMRA (2005), Hendriks and Pietersen (2000)
Brazil	15	8	Hendriks and Pietersen (2000)
Norway	30	7	Hendriks and Pietersen (2000)

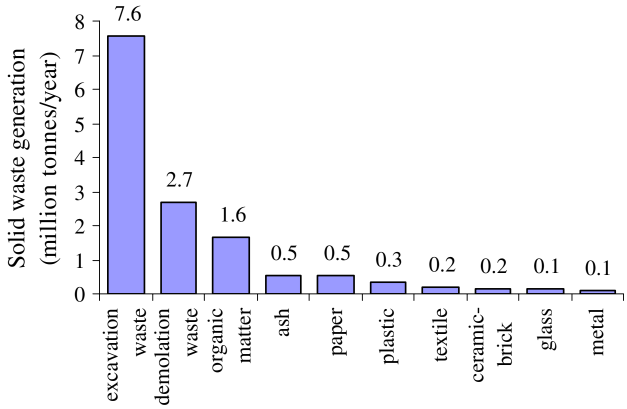

Fig. 2 Current status of solid waste generation in Istanbul

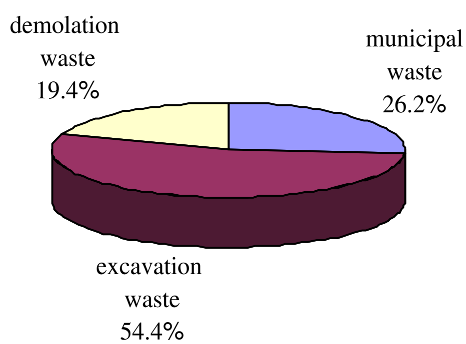

Fig. 3 Current status of solid waste distribution in Istanbul

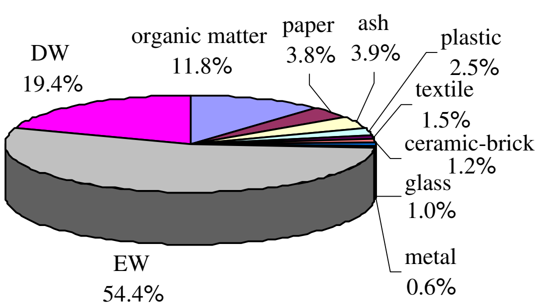

Fig. 4 Current status of municipal waste distribution in Istanbul

Details regarding railway lines currently under construction in Istanbul are given in Table 2 and Fig. 5. Railway lines in the project stage or tender stage are given in Table 3 (IMM 2004).

Environmental problems caused by subway excavations

Transporting and storing excavated material

Almost all land in Istanbul is inhabited. Therefore, it is of utmost importance to store and recycle excavated material obtained either from metro excavations or other construction activities, causing minimal damage and disturbance to the city.

The collection, temporary storage, recycling, reuse, transportation and destruction of excavated material and construction waste are controlled by environmental law number 2872. According to this law, it is essential that:

1. Waste must be reduced at its source.
2. Management must take necessary precautions to reduce the harmful effects of waste.
3. Excavated material must be recycled and reused, especially within the construction infrastructure.
4. Excavated material and construction waste must not be mixed.
5. Waste must be separated from its source and subjected to "selective destruction" in order to form a sound system for recycling and destruction.
6. Producers of excavated material or construction waste must provide required funds to destroy waste.

According to environmental laws, municipalities are responsible for finding areas within their province limits to excavate and operate these systems. Both the Istanbul Metropolitan Municipality Environmental Protection and Waste Recycling Company are the foundations that actively carryout all operations regarding excavated material.

Table 2 Ongoing railway systems in Istanbul

Project	Line	Length (km)	Cost (Million USD)	Capacity (passengers/h/direction)
Metro	Levent–Darüşşafaka (1)	8.0	253	70,000
Metro	Kadıköy–Kartal (2)	21.6	1,100	65,000
Metro	Taksim–Yenikapı (3)	5.2	370	70,000
Light rail transport	Aksaray–Yenikapı (4)	0.7	56	35,000
Light rail transport	Otogar–Kirazlı 1 (5)	5.8	225	35,000
Tram	Topkapı–Sultan Çiftliği (6)	14.4	205	15,000
Metro	Kirazlı 1–Başakşehir (7)	11.7	630	70,000
Metro	Güney sanayi–Olimpiyat (8)	4.1		70,000
Metro	Kadıköy–Eminönü (9)	13.6	850	75,000
Total		85.1	3,689	389,000

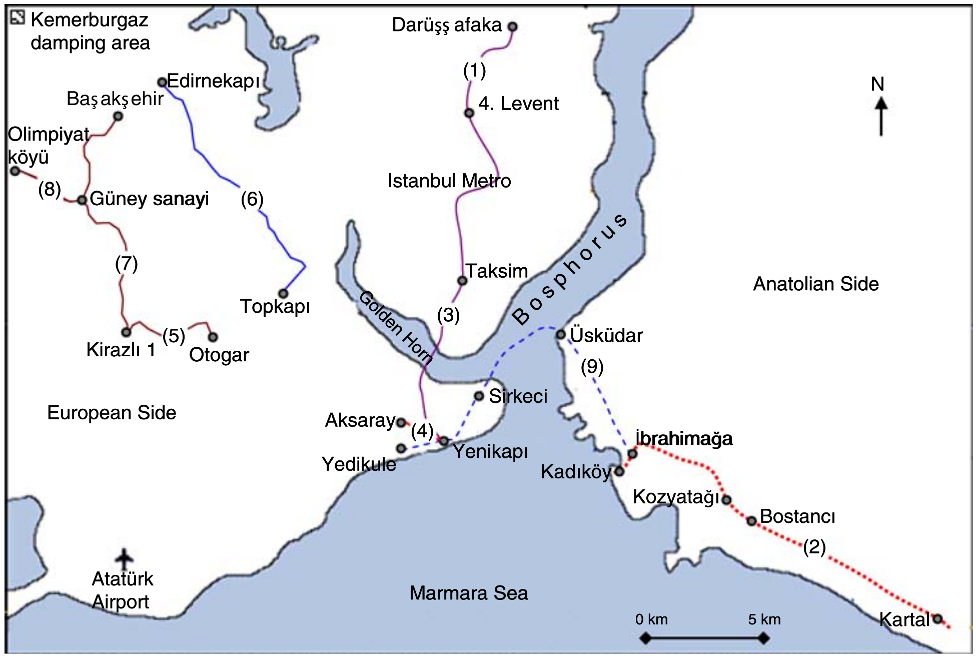

Fig. 5 Ongoing railway system studies in Istanbul

Table 3 Railway lines in project or tender stage in Istanbul

Project	Line	Length (km)	Cost (Million USD)	Capacity (passenger/h/direction)
Metro	Yenikapı–Kirazlı 1	11.8	600	70,000
Metro	Mahmutbey–Başakşehir	14.2	700	70,000
Metro	Beşiktaş–Şişli–Otogar	14.0	675	70,000
Light rail transport	Üsküdar–Tepeüstü (1. phase)	11.5	400	35,000
Light rail transport	Tepeüstü–Samandıra (2. phase)	9.5	400	35,000
Light rail transport	Göztepe–Ümraniye	5.0	200	35,000
Light rail transport	Kartal–Kurtköy–Havaalanı	9.6	450	35,000
Light rail transport	Bakırköy–Beylikdüzü	21.0	815	35,000
Tram	Zeytinburnu–Bakırköy	3.7	27	15,000
Tram	Haliç Kıyısı–GOP	16.0	185	15,000
Total		116.3	4,452	430,000

Since dumping areas have limited space, they are quickly filled, without any available plausible solution for remediation. In addition, existing dumping areas are far away from metro excavation areas. This means that loaded trucks are competing with city traffic, causing traffic congestion with their low speed and pollutants dropping off their wheels or bodies. Furthermore, this results in a loss of money and labour.

Details regarding excavated material pertaining to ongoing railway systems in Istanbul are given in Table 4. The cross section in the table represents only tunnels on the main line. Given the fact that the swelling value of rock is 1.4–1.5, together with the diameter values given above, the approximate amount of excavated material from ongoing railway excavation will be equal to 12 million m^3. All tunnels have been excavated with new Austrian tunnelling method (NATM), earth pressure balance method (EPBM), tunnel boring machine (TBM), and cut and cover method.

Existing dumping areas in Istanbul are listed in Table 5. When Tables 4 and 5 are examined together, it can be seen that existing dumping areas can only accommodate material excavated from the metro construction. Another important matter according to Table 5 is that 93% of existing dumping areas are on the European side of Istanbul, with 88% of them in Kemerburgaz. Thus, all excavated material on the Anatolian side must cross over European site every day for a distance of approximately 150 km. Every day, on average, 3,000 trucks carry various types of excavated material to Kemerburgaz from other parts of Istanbul. This leads to a waste of time and increased environmental pollution.

Table 4 Excavation volume occurred from ongoing railway systems in Istanbul

Type	Lines	Construction method	Excavation (m^3)
Metro	Levent–Darüşşafaka	NATM	819,264
Metro	Kadıköy–Kartal	EPBM + TBM	2,368,096
Metro	Taksim–Yenikapı	NATM	710,029
Metro	Bağcılar–Başakşehir	TBM	1,240,320
Metro	İkitelli–Olimpiyat Köyü	NATM	435,200
Light rail transport	Aksaray–Yenikapı	NATM	95,581
Light rail transport	Otogar–Bağcılar	EPBM	402,560
Tram	Vezneciler–Sultan Çiftliği	Cut and cover	1,011,200
Metro	Kadıköy–Eminönü	Slurry TBM	720,000
Total			7,802,250

Table 5 Existing dumping areas in Istanbul

Name of firm	Dumping area	Capacity (m^3)	%
Istac company	Kemerburgaz	10,444,085	69.6
Three others companies	Various	3,540,073	3.3
Total of European side		13,984,158	93.3
Total of Anatolian side (six companies)	Various	1,011,486	6.7
Total		14,995,644	100.0

Another problem related to excavation is that the materials, obtained from EPBM machines (Fig. 6) and muddy areas, cannot be directly sent to dumping facilities. They have to be kept in suitable places, so that water can be drained off from the material and then sent to proper facilities. However, this causes muddy material to drop from trucks, causing increased litter in cities (Fig. 7).

Traffic jam

Since most of the railway constructions are carried out in the most densely populated areas, city traffic must be closed and redirected during the construction. In most cases, an entire area must be closed for traffic. For example, Üsküdar square is now closed due to the Marmaray project and most bus stops and piers have been moved to other locations.

With cut and cover constructions, the case becomes even more complicated. In this case, an entire route is closed to traffic because cut and cover tunnels are constructed across streets. In order to ensure that machine operation and construction can continue uninterrupted and to minimize the risk of accidents to the people living around the construction zone, streets are either totally closed to traffic or traffic is redirected (Figs. 8, 9). This causes long-term difficulties. For example, shop owners on closed streets have difficulties

Fig. 6 Muddy material resulting from EPBM

Fig. 7 Excavated material stocked for draining

Fig. 8 Redirected traffic during tram construction

Fig. 9 Sultançiftliği–Edirnekapı tram construction and closed streets

Fig. 10 A shaft that is 5–6 m away from an apartment

Fig. 11 Mud that has spread over Eyüp Aksoy Street during the Kadıköy–Kartal Metro excavation

reaching their shops, stocking and transporting their goods and retaining customers.

Noise and vibration

For metro excavations, a lot of different machines are used. These machines seriously disturb the environment with their noise and vibrations. In some regions, excavation may be as close as 5–6 m away from inhabited apartment blocks (Fig. 10). In such cases, people are disturbed as excavation may take a significant period of time to be completed.

Drilling–blasting may be needed in conventional methods for drilling through hard rock. In this case, no matter how controlled the blasting is, people who are living in the area experience both noise and vibrations. Some become scared, thinking that an earthquake is happening. In blasting areas, the intensity of vibrations is measured. In order to keep them within accepted limits, delayed capsules are used.

In order to minimize vibration and noise caused by machines and to reduce the effects of blasting, working areas are surrounded by fences. Superficial blasting shaft rims are covered with a large canvas and fences are covered with wet broadcloths. However, these precautions can only reduce negative effects; they cannot totally eliminate them.

The formation of dust and mud

Depending on the season, both dust and mud disturb the environment. During removal of excavated material, especially muddy material, trucks may pollute the environment despite all precautions taken. Mud that forms around the excavation area may slide down the slope and cover the ground (Fig. 11). In this case although roads are frequently cleaned, the environment is still disturbed. Trucks, which travel from dumping areas to areas that are muddy cannot enter traffic until their wheels and bodies are washed. However, this cannot prevent the truck wheel from dropping mud on the roads while on move.

Interrupted utilities

Interrupted utilities are also one of the most crucial problems facing citizens during excavation projects due to the fact that telephone, natural gas, electricity, water, and infrastructure lines must be cut off and moved to other areas (Fig. 12). During the transfer of these lines, services may remain unavailable for some time. Some institutions will not allow others to do this and carry out operations themselves. With so many providers conducting individual moves, services may be interrupted for an extended term of time.

Damage to neighbouring buildings

Metro excavations cause deformations around the excavation area (Fig. 13). These deformations are continuously checked and efforts are made to keep them under control. However, some deformations may become extensive; including cracks or even collapses of neighbouring buildings. Every metro tunnel excavation in Istanbul causes problems as mentioned earlier. These kinds of problems are more frequent in shallow tunnels. In such cases, although people's financial losses are compensated, their overall livelihood and way of life is compromised. For example, in a landslip during the first stage of the Istanbul Metro excavation, five people died. Obviously, no amount of money can compensate the death of a person.

Suggestions for remedying environmental problems

Environmental problems that arise during tunnel excavations include traffic jams, noise, vibrations, dust, mud and

Fig. 12 Infrastructure transfers during metro excavations

Fig. 13 Deformation that occurred in the pavement during the Kadıköy–Kartal Metro excavation

deformation of surrounding buildings. Some possible solutions are recommended as listed below:

- In big cities, railway systems are crucial to city transportation. However, a tram should not be considered as a viable railway system due to its low transportation capacity (approximately 1/3 of the metro). At the same time, a tram uses the same route as wheeled transportation devices. Therefore, trams occupy the same space as regular traffic and do not offer substantial advantages.
- The most crucial problem facing metro excavations is not providing railway lines in a timely manner. Proof of this exists in big cities, including London, Paris, Moscow or Berlin, where metro lines of over 500 km exist. However, in Istanbul, there are only 8 km of metro line. Had the metro been built earlier when the city was not overcrowded, many problems facing the city would not currently exist. Now, officials must do their best to reduce troubles that future generations are likely to face.
- Any kind of railway construction carried out above the ground causes serious problems to people living in the area. In addition, these kinds of construction cause both noise and litter. All railway lines are constructed completely underground in many parts of the world. This has two advantages; first, since excavation is carried out underground, it causes minimal interruption in utilities and provides a more comfortable area to work. Thus, the environment is exposed to very little damage because all operations are carried out underground.
- Before beginning metro excavations, the route must be carefully examined for weaknesses in infrastructures and existing historical buildings. Otherwise, these elements cause problems, including interruptions in

excavation when work must stop until the environment is stabilized. An example of this is that during the second stage of the Taksim–Yenikapı route of the Istanbul Metro, the construction of the Haliç Bridge could not be started due to historical ramparts.

- A lack of coordination among related institutions providing utility services is a major problem. Therefore, founding of an institution that strictly deals with relocating natural gas lines, telephone lines, sewer systems, and electricity will definitely accelerate the transfer of energy lines and avert accidents and inconveniences caused by this lack of coordination.
- In order to increase benefits of railway systems both in construction and operational stages, projects must be continuously revised from time to time. This is the main problem facing Istanbul metro excavations. It has taken 110 years to restart metro projects in Istanbul, with the last project, the opening of the Karaköy tunnel, established in 1876 (Ocak 2004). From this time onward, initiated projects must have been stable and continuous. In 1935, 314,000 passengers were travelling daily. In the 1950s, the total length of tram lines reached 130 km (Kayserilioglu 2001). However, as the trolleybus was introduced in 1961, all tram lines on the European side, and in 1966, all lines on the Anatolian side were removed in order to make way for private vehicles (Kayserilioglu 2001).

Results and discussion

TBM and classic tunnel construction methods are widely used in Istanbul for different purposes, like metro, sewerage and water tunnels. Waste from rock is rarely used as construction material as the suitability of the material for this purpose is not well examined. However, it is believed that the muck may be used for some applications. If this suitability is realized, cost savings may be significant for tunnel construction, where the use of aggregate is a common requirement. A review of standard construction aggregate specifications indicates that hard rock TBM waste would be suitable for several construction applications, including pavement and structural concrete (Gertsch et al. 2000). Size distributions of waste materials produced by tunnel boring machines are less (up to 125 mm) than the waste materials produced by using classical construction methods. Muck size distribution is uniform, generally larger (up to 30–40 cm) and can be changed to meet a wide range of classical construction methods, making the reuse of waste more common. The waste product is used as construction materials. Fifty-seven percent of EW generated during tunnel excavations result from classical tunnel construction, 33.5% from TBM, while the remaining percentage stems from EPBM and slurry TBM. Different from TBM waste materials generated by EPB and slurry, TBM include mud and chemical materials.

The annual quantity of EW generated in Istanbul is approximately 7.6 million tons. 13.8% of this total is clay and fill. The rest is composed of rock. The distribution of the materials can be seen in Appendix 1. Rock material can be properly used in roadway structures, fillings, road slopes, for erosion control and as a sub-base material, as long as it conforms to local standards (TS 706, TS1114) (Appendix 2). Sand and clay have properties appropriate for use as raw materials for industrial use, depending on local standards. More studies should be completed to determine other potential uses for this material. Only 10% of rock material generated during tunnel excavation can be evaluated. A large percentage of soil material, nearly 70,000 m^3, can be recycled.

Generally, for any subway construction project, plans for recycling waste materials should be implemented prior to work commencement. These plans should identify which types of waste will be generated and the methods that will be used to handle, recycle and dispose these materials. Additionally, areas for temporary accumulation or storage should be clearly designated.

A waste management plan directs construction activities towards an environmentally friendly process by reducing the amount of used and unused waste materials. Environmental and economic advantages occurring when waste materials are diverted from landfills include the following (Batayneh et al. 2007):

1. The conservation of raw materials
2. A reduction in the cost of waste disposal
3. An efficient use of materials.

EW materials must be kept clean and separate in order for them to be efficiently used or recycled. Storage methods should be investigated to prevent material from being lost due to mishandling. In addition, orders for materials should be placed just before work commences. To complete a waste management plan, an estimation of the amount and type of usable and unusable EW materials expected to be generated should be developed. Listing all expected quantities of each type of waste will give an indication of what type of management activities are appropriate for each specific waste material. At each stage of excavation, specific ways to reduce, reuse or recycle produced EW should be implemented. The flow chart in Appendix 3 includes suggestions for an EW management plan.

This paper focuses on EW produced by metro tunnel excavation through hard rock and soil. TBM and classical tunnelling wastes can be successfully used in many construction and speciality applications, including aggregates, erosion control, roadway structures, fill, sub-base material and road slopes. In order to minimize negative effects caused by excavated material both on the environment and on people, it must be reduced at its source. Including forcible decrees through the acceptance of environmental laws would also be useful. Soil and clay material, excavated through the use of EPBM machines, must be reused. It is possible to separate clay and sand, making its reuse possible and minimizing harmful environmental effect. Waste and recycling management plans should be developed for any construction project prior to commencement in order to sustain environmental, economic, and social development principles.

Waste management is a critical issue facing the construction industry in Istanbul as the industry is one of the biggest generators of pollution. During different excavation projects, construction, demolitions and domestic activities, Istanbul produces about 14 million tons of solid waste each year, posing major environmental and ecological problems, including the need for a large area of land to be used as storage and disposal facilities. This waste consists of EW (7.6 million tons), DW (2.7 million tons) and municipal waste (3.7 million tons). The recycling rate of municipal waste is only 7%. The recycling rate of EW and DW is below 10% (IMM 2007).

Appendix 1

See Table 6

Table 6 Generated EW and its properties

Lithelogy	Capacity (tons/ years)	Unconfined compressive strength (MPa)	Modulus of elasticity (GPa)	Density (kN/m^3)	%
Claystone	1,105,018	43.7	10.1	25.7	14.6
Diabase	28,852	61.3	13.1	24.4	0.4
Limestone	1,205,468	43.9	10.5	26.3	15.9
Mudstone	180,852	29.4	8.3	24.8	2.4
Sanstone	2,694,479	56.0	11.8	26.2	35.6
Shale	375,685	43.1	12.9	24.8	5.0
Siltstone	942,468	60.0	17.0	26.0	12.4
Fill	474,946	–	–	19.0	6.3
Claysand	566,422	–	–	20.0	7.5
Total	7,574,188				100.0

Appendix 2

See Table 7

Table 7 Generated soft materials and its properties

Material	Liquid limit (%)	Plasticity limit (%)	Plasticity index (%)
Clay	26–67	19–34	11–39
Sand	32–50	25–34	11–15

Appendix 3

See Fig. 14

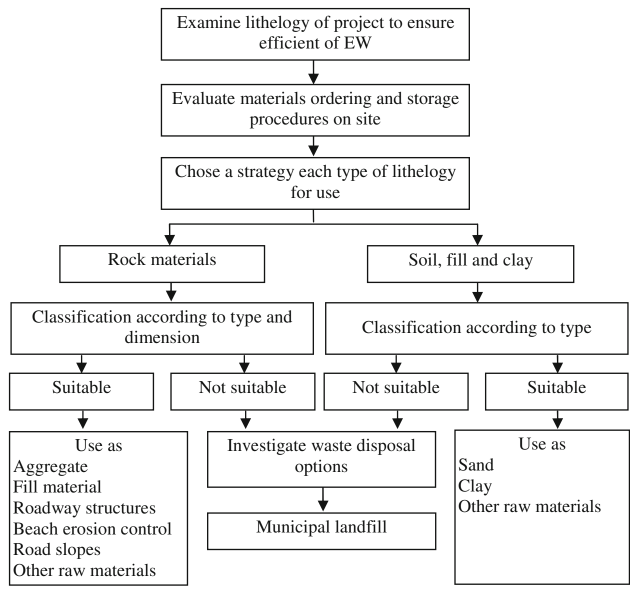

Fig. 14 Flow chart for EW management

References

Adamov EO, Ganev IK, Orlov VV (1992) Achievement of radiation equivalency in management of nuclear-power radioactive waste. At Energy 73(1):44–50

Ahumada R, Rudolph A, Contreras S (2004) Evaluation of coastal waters receiving fish processing waste: Lota bay as a case study. Environ Monit Assess 90(1–3):89–99

Akhtar M, Mahmood I (1996) Organic soil amendments in relation to nematode management with particular reference to India. Biomed Life Sci 1(4):201–215

Ali MF, Nahid M, Siddiqui S, Redhwi HH (2004) Study on the conversion of waste plastics/petroleum resid mixtures to transportation fuels. J Mater Cycles Waste Manage 6(1):27–34

Al-Masri MS, Suman H (2003) NORM waste management in the oil and gas industry: the Syrian experience. J Radioanal Nucl Chem 256(1):159–162

Batayneh M, Marie I, Asi I (2007) Use of selected waste materials in concrete mixes. Waste Manage 27:1870–1876

Bell DH, Wilson DD (1988) Hazardous waste disposal in New Zealand. Bull Eng Geol Environ 37(1):15–26
Boadi KO, Kuitunen M (2003) Municipal solid waste management in the Accra Metropolitan Area, Ghana. Environmentalist 23(3):211–218
Bruun S, Hansen TL, Christensen TH, Magid J, Jensen LS (2006) Application of processed organic municipal solid waste on agricultural land—a scenario analysis. Environ Model Assess 11(3):251–265
Chen X, Wright JV, Conca JL, Peurrung LM (1997) Evaluation of heavy metal remediation using mineral apatite. Water Air Soil Pollut 98(1–2):57–78
CMRA: Construction Materials Recycling Association (2005) http://www.cdrecycling.org/
Debra R, Reinhart G, Frederick G (1991) The assimilation of organic hazardous wastes by municipal solid waste landfills. J Ind Microbiol Biotechnol 8(3):193–199
Edwards CA, Dominguez J, Neuhauser EF (1998) Growth and reproduction of *Perionyx excavatus* (Perr.) (Megascolecidae) as factors in organic waste management. Biol Fertil Soils 27(2):155–161
Garnier M, Porto AL, Marini R, Leone A (1998) Integrated Use of GLEAMS and GIS to prevent groundwater pollution caused by agricultural disposal of animal waste. Environ Manage 22(5): 747–756
Gertsch L, Fjeld A, Nilsen B, Gertsch R (2000) Use of TBM muck as construction material. Tunn Undergr Space Technol 15(4):372–402
Hayashi S, Nomaguchi K, Okusawa T, Yokomizo O, Ishigaki Y, Ishimaru H (2000) Feasibility investigation on a dual waste-plastics recycling system concept. J Mater Cycles Waste Manage 2(1):57–62
Hendriks CF, Pietersen HS (2000) Sustainable raw materials: construction and demolition waste. RILEM Publication, Cachan Cedex
Huang GH, Sae-Lim N, Liu L, Chen Z (2001) An interval-parameter fuzzy-stochastic programming approach for municipal solid waste management and planning. Environ Model Assess 6(4): 271–283
Huang O, Wang O, Dong L, Xi B, Zhou B (2006) The current situation of solid waste management in China. J Mater Cycles Waste Manage 8:63–69
Idris A, Bulent Inanc B, Hassan MN (2004) Overview of waste disposal and landfills/dumps in Asian countries. J Mater Cycles Waste Manage 6(2):104–110
IMM: Istanbul Metropolitan Municipality (2004) Commission report for transportation system (draft). http://www.ibb.gov.tr
IMM Istanbul Metropolitan Municipality (2005) Preliminary report of city and transportation commission. Istanbul City Transportation Council. http://www.ibb.gov.tr/ibbtr/140/14005/1400501/ulasimraporu.htm
IMM Istanbul Metropolitan Municipality (2007) Various unpublished tender documents and official knowledge
Jackson MM (2006) Organic liquids storage tanks volatile organic compounds (VOCS) emissions dispersion and risk assessment in developing countries: the case of Dar-Es-Salaam City, Tanzania. Environ Monit Assess 116(1–3):363–382
Karani P, Stan Jewasikiewitz M (2007) Waste management and sustainable development in South Africa. Environ Develop Sustain 9(2):163–185
Kasakura T, Noda R, Hashiudo K (1999) Trends in waste plastics and recycling. J Mater Cycles Waste Manage 1(1):33–37
Kato K, Nomura S, Uematsu H (2003) Waste plastics recycling process using coke ovens. J Mater Cycles Waste Manage 5(2):98–101
Khan HU, Husain T, Khan SM (1987) Solid waste management practices in the Eastern Province of Saudi Arabia. Environ Manage 11(6):729–734
Krinitsyn AP, Strikhar OL, Shcherbin VN (2003) Management of liquid radioactive waste from the shelter. Radiochemistry 45(5):512–517
Minh NH, Minh TB, Kajiwara T, Kunisue T, Subramanian A, Iwata H, Tana TS, Baburajendran R, Karuppiah S, Viet PH, Tuyen BC, Tanabe S (2006) Contamination by persistent organic pollutants in dumping sites of Asian developing countries: implication of emerging pollution sources. Arch Environ Contamin Toxicol 50(4):474–481
Mohanty RK (2001) Feeding management and waste production in semi-intensive farming of penaeus monodon (fab.) at different stocking densities. Aquac Int 9(4):345–355
Nishino J, Itoh M, Ishinomori T, Kubota N, Uemichi Y (2003) Development of a catalytic cracking process for converting waste plastics to petrochemicals. J Mater Cycles Waste Manage 5(2):89–93
Ocak I (2004) A statistical approach on the effect of rock properties through excavations of metro tunnel on excavation rate, surface settlement and convergence, Ph.D. Thesis, Osmangazi University, Institute of science and technology, Eskisehir
Okuda I, Thomson (2007) Regionalization of municipal solid waste management in Japan: balancing the proximity principle with economic efficiency. Environ Manage 40(1):12–19
Rocco P, Zucchetti M (1997) Management strategy to reduce the radioactive waste amount in fusion. J Fusion Energy 16(1–2): 141–148
Rodgers DW, Evans DW, Sheehan LV (1996) Toxicity reduction of Ontario hydro radioactive liquid waste. Water Air Soil Pollut 90(1–2):219–229
Staudt E, Schroll M (1999) The German packaging ordinance: the questionable effects of a fragmentary solid waste management approach. J Mater Cycles Waste Manage 1(1):17–24
Sullivan PJ, Yelton JL (1988) An evaluation of trace element release associated with acid mine drainage. Environ Geol 12(3):181–186
Vasile C, Brebu MA, Karayildirim T, Yanik J, Darie H (2006) Feedstock recycling from plastic and thermoset fractions of used computers (I): pyrolysis. J Mater Cycles Waste Manage 8(2):99–108
Vlachos E (1975) Social aspects of solid wastes development and management: refuse, recovery, and reuse. Water Air Soil Pollut 4(2):293–301
Walker DD, Gylling B, Strom A, Selroos JO (2001) Hydrogeologic studies for nuclear-waste disposal in Sweden. Hydrogeol J 9(5):419–431
Wang FS (2001) Deterministic and stochastic simulations for solid waste collection systems—a SWIM approach. Environ Model Assess 6(4):249–260
Winkler J (2005) Comparative evaluation of life cycle assessment models for solid waste management. Int J Life Cycle Assess 10(2):156–157
Yang HL, Innes R (2007) Economic incentives and residential waste management in Taiwan: an empirical investigation. Environ Resource Econ 37(3):489–519