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CHAPTER 23: SUBSEA TELECOMMUNICATIONS

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SUBSEA TELECOMMUNICATIONS

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Introduction

Send an email overseas, download a video, search the internet or make an airline booking – these everyday actions will most likely involve subsea fibre-optic cables. Over 95 per cent of international communications and data transfer are via the global subsea cable network – a general collective term used here to encompass the many cable systems that are owned and operated by independent commercial entities. That dominance of cables reflects their ability to reliably and rapidly transmit large volumes of data and voice traffic in a secure and economical manner (Carter *et al.*, 2009; Burnett *et al.*, 2013). Although satellites carry <5 per cent of international traffic, they are still suited for providing worldwide coverage and television broadcasts as well as bringing communications to remote areas not linked to cables and to regions prone to natural disasters.

Such is the reliance of the world's economy, security and social framework on subsea cables that they are now regarded as *critical infrastructure* and hence are worthy of the best possible protection (e.g. Lacroix *et al.*, 2002; ACMA, 2015). To emphasise this point, the SWIFT (Society for Worldwide Interbank Financial Telecommunication) provides a service that transmits financial data between 208 countries via subsea cables. In 2004, up to $US7.4 trillion were transferred or traded on a daily basis. Thus a failure of the subsea network, no matter how brief, invites large financial repercussions (Rauscher, 2010). Accordingly, cable protection has become a high priority especially at this time of a rapidly increasing human presence offshore. The last two decades have witnessed a marked expansion of shipping, offshore renewable energy generation, hydrocarbon and mineral exploration, industrial fishing and marine research, all of which are taking place against a backdrop of ocean change forced by a climate under the influence of anthropogenic greenhouse gases (e.g. Halpern *et al.*, 2008; UNEP-WCMC, 2009; Smith *et al.*, 2010; IPCC, 2013).

Subsea cables

Around 1.5 million kilometres of fibre-optic telecommunications cables have been laid on the ocean floor since 1988 when the first trans-oceanic system, *TAT-8*, was installed to link the USA, UK and France (Figure 23.1). For water depths exceeding *ca.* 2000 m – an approximate limit for bottom trawl fishing, which is a major cause of cable damage (e.g. Mole *et al.*, 1997;

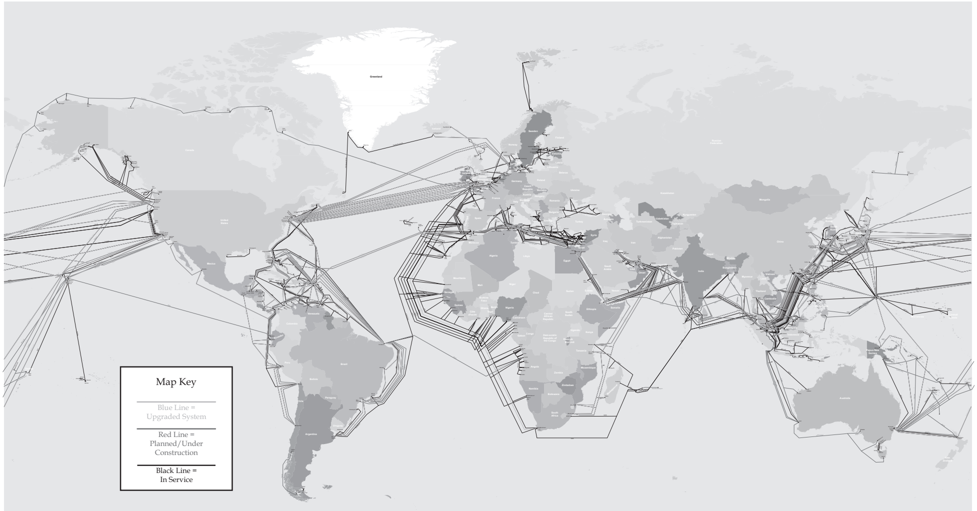

Figure 23.1 Submarine cables of the world
Source: Courtesy of Submarine Telecoms Forum.

Kordahi and Shapiro, 2004) – fibre-optic cables are typically laid on the seabed surface and are about the size of a domestic garden hose, i.e. between 17 and 22 mm diameter. This is the deployment made for most of the global network as water depths >2000 m account for 84 per cent of the ocean. In depths <2000 m, cables are up to 50 mm diameter due to the addition of steel wire armour for protection especially in continental shelf and slope waters shallower than 200 m (Kordahi *et al.*, 2007). These shallow-water cables are also commonly buried below the seabed for additional protection.

Deep-water cables consist of (from inside to outside; Figure 23.2) (i) hair-like glass fibres encased in a steel tube filled with a thixotropic medium, (ii) a covering of steel wire strands to provide strength, (iii) a copper-based composite conductor to carry electrical power and (iv) a protective insulating sheath of polyethylene (Hagadorn, 2009). For water depths <2000 m, various layers of galvanized steel wire armour are applied according to the nature of the risk. These armoured types are finally wrapped in a hard-wearing polyethylene sheath. Because light signals passing along the optical fibres periodically require amplification, repeaters are installed at intervals approaching 100 km along a cable route. Powered via the copper-based conductor, modern repeaters now use optical amplifiers that are essentially glass fibres containing the rare earth element, erbium. When energised by lasers, these erbium-doped fibres amplify the light signals sending them on their way to the next repeater.

The rapidly evolving fibre-optic technology is the latest evolutionary phase in undersea communications that began symbolically in 1850 with the laying of a telegraph link between Dover and Calais. No more than a copper wire insulated by the natural polymer, *gutta percha*, the cable could not withstand the strong waves and currents of the English Channel and failed after a few messages (Carter *et al.*, 2009). A strengthened version was deployed a year later and survived for a decade, which was long enough to encourage installation of other short-haul cables around Europe. In 1858, the first trans-Atlantic telegraphic cable was laid between Ireland and Newfoundland (Gordon, 2002; Ash 2013). Although it operated for only 26 days, it was a start. Following other failed attempts that encouraged improvements in cable design and laying techniques, a reliable operating system was installed in 1866 from the famed cable ship, *Great*

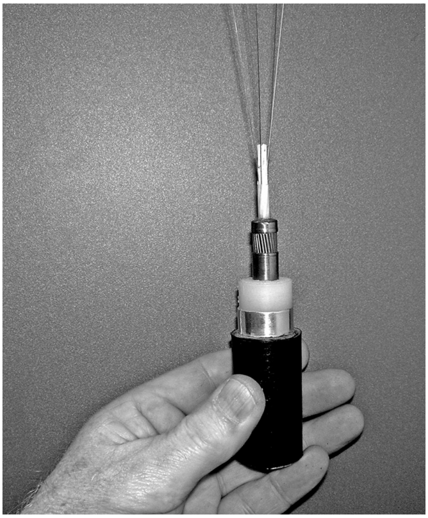

Figure 23.2 A section of lightweight cable designed for deployment on the seabed surface, nominally in water depths exceeding 2000 m, which is the approximate depth limit of deep trawl fishing, a major cause of cable faults

Source: L. Carter.

Eastern. Advances in cable design and construction improved reliability and transmission speeds, which increased from 12 words/minute for the first cables to 200 words/minute by the 1920s. In the 1930s experiments with polyethylene encased coaxial cables were underway and, along with the development of repeaters, set the scene for cables to carry multiple voice channels. In 1955–56 this became a reality with the laying of the coaxial system, TAT-1, between Scotland and Newfoundland. The *telephonic era* was born and the *telegraphic era* became history. On the first day of operation in 1956, 707 telephone calls were made between the USA and UK – a major improvement on telegraphic links but not enough to match developing satellite communications in the late 1970s and 1980s. Even though trans-Atlantic cables achieved capacities of up to 4000 telephone channels, they were mainly viable on major traffic routes. Satellites dominated global communications through the 1980s. However, the laying of the first fibre-optic, trans-oceanic link in 1988 heralded a fundamental shift in communications. The carrying capacity of fibre-optic cables was much larger than that of their coaxial counterparts and so the transition to the *fibre-optic era* began. Today, a cable link, such as that between the USA and Japan, can accommodate 23 million simultaneous voice calls or around 1.9 million simultaneous transfers of 1 Mb files (PC Landing, 2013). Equally important, the rapid evolution of fibre-optic cables coincided with the development of the internet. It was a fortuitous timing. Cables could efficiently and rapidly transfer large volumes of information and data around the world whereas the internet made that material available to a wide range of users with an equally wide range of applications.

International law and submarine cables

The International Convention for the Protection of Cables[1] is the foundation of modern international law for submarine cables as contained in the United Nations Convention on the Law of the Sea (1982) ('UNCLOS') (Burnett *et al*., 2013). UNCLOS treats cables the same based on their purpose. If a cable is used for dual purposes, telecommunications and science or telecommunications and natural resources, it will in addition to the UNCLOS legal regime governing telecommunication cables be governed by the legal regime for marine scientific research or natural resources as the case may be. UNCLOS expressly provides for the fundamental freedom to lay and maintain submarine cables in ten articles.[2]

UNCLOS establishes the rights and duties of all States, balancing the interests of coastal States in offshore zones with the interests of all States in using the oceans. Coastal States exercise sovereign rights and jurisdiction in the exclusive economic zone (EEZ) and upon the legal continental shelf (LCS) for the purpose of exploring and exploiting their natural resources, but other States enjoy the freedom to lay and maintain submarine cables in the EEZ and upon the LCS. In archipelagic waters and in the territorial sea, coastal States exercise sovereignty and may establish conditions for cables or pipelines entering these zones. Such conditions on cables should generally be effective only within the territorial and archipelagic seas and not extend into the EEZ or high seas.[3] The laying and maintenance of submarine cables is considered a reasonable use of the sea and coastal States benefit from them.

Outside of the territorial sea, the core legal principles applying to international cables can be summarised as follows:[4]

- the freedoms to lay, maintain and repair cables outside of territorial seas, including cable route surveys incident to cable laying[5] (Nordquist *et al.*, 1993);
- the requirement that parties apply domestic laws to prosecute persons who endanger or damage cables wilfully or through culpable negligence;[6]
- the requirement that vessels, unless saving lives or ships, avoid actions likely to injure cables;
- the requirement that vessels must sacrifice their anchors or fishing gear to avoid injury to cables;
- the requirement that cable owners must indemnify vessel owners for lawful sacrifices of their anchors or fishing gear;
- the requirement that the owner of a cable or pipeline, who in laying or repairing that cable or pipeline causes injury to a prior laid cable or pipeline, indemnify the owner of the first laid cable or pipeline for the repair costs;
- the requirement that coastal States along with pipeline and cable owners shall not take actions that prejudice the repair and maintenance of existing cables.

Careful route planning helps to avoid damage to cables (Wagner, 1995). With respect to potential adverse impacts caused by submarine cables, UNCLOS indirectly takes into account their potential environmental impact by distinguishing cables from submarine pipelines; that is, on the continental shelf it allows a coastal State to delineate a route for a pipeline but not for a cable.[7] The reason for this distinction is that there is a need to prevent, reduce and control any pollution that may result from pipeline damage. By comparison, damage to an ocean cable does not involve pollution (Nordquist *et al.*, 1993), but may significantly disrupt international communications or electrical power distribution.

States treat international cables in national maritime zones as critical infrastructure that deserves strong protection to complement traditional international cable law. Australia, consistent with international law, has legislated to protect its vital cable links by creating seabed protection zones that extend out to 2000 m water depth.[8] Bottom trawling and other potentially destructive fishing practices, as well as anchoring, are prohibited inside these zones. New Zealand has enacted legislation that established no fishing and anchoring zones around cables.[9] The trend is expected to continue because most nations depend upon cables for participating in the global economy and for national security. These developments go hand in hand with conservation, as restrictions on trawling to prevent cable damage can also provide direct benefits for biodiversity by protecting vulnerable ecosystems and species such as corals and sponges (Carter *et al.*, 2009).

Since UNCLOS, the parties to the UNESCO Convention on Underwater Cultural Heritage (2001) agreed to exempt cables from that treaty because of the specific provisions of UNCLOS and the agreement of the parties that cable laying and maintenance posed no threat to underwater cultural heritage.

The laying and maintenance of cables is a reasonable use of the sea, and in 166 years of use, there has been no irreversible environmental impact from them. UNCLOS and State practice have provided adequate governance for international cables outside national waters, and State practice increasingly recognises the importance of protecting cables from activities that could damage them.

Protecting the network in a busy ocean

About 150 to 200 cable faults occur annually around the world. Analyses of fault records show that *ca.* 70 per cent and more of all faults result from human activities, notably fishing and ships' anchoring (Kordahi and Shapiro, 2004; Kordahi *et al.*, 2007; Wood and Carter, 2008). Damage caused by natural phenomena such as submarine landslides tends to be <10 per cent but may be locally higher in hazard-prone regions, in particular the seismically active rim of the Pacific Ocean (see Natural hazards). Faults resulting from component failure have a long-term average of 7 per cent but over the past two decades it has dropped below 5 per cent, reflecting the improved reliability of cables (Kordahi *et al.*, 2007). Around 20 per cent of faults are classified as 'unknown', that is there is no conclusive evidence regarding the cause of the fault such as the presence of trawl gear or furrows in the seabed produced by a dragged anchor.

Commercial fishing appears to be the prime cause of cable faults (Drew, 2009). Bottom trawl fishing is especially hazardous because it is a widespread and repetitive practice. The hazard relates to heavy trawl doors or *otter boards* ploughing the seabed and damaging any cable in their path. Several different scenarios are possible; (i) the otter boards pass over the cable and scrape the sheathing without causing significant damage, (ii) the boards break the protective and insulating sheathing to allow seawater to make contact with the live conductor and produce a *shunt fault*, (iii) the cable is dragged and bent sufficiently to damage the glass fibres to form an *optical fault* and (iv) the cable is severed. Fishing operations using an anchor or grapnel also pose a significant risk. Grapnels may be towed by fishing vessels to recover lost gear. If a grapnel snags a cable on or under the seabed, the momentum of the towing vessel may bend, stretch or ultimately break a cable depending on its diameter and amount of wire armouring. A non-armoured or light-weight cable may break under a few tonnes strain whereas a double armoured cable breaks at 40 tonnes strain or more. Anchors are used to install static fishing devices ranging from lobster pots to large fish-trapping systems. The hazard arises when large devices are indiscriminately installed over subsea cables. If these static devices are poorly anchored and eventually drift with the currents than anchors may be dragged onto cables.

The anchoring of ships is the other major cause of faults. Incorrectly stowed anchors are known to break free while a ship is underway. As a result, anchors can be towed long distances over the seabed unbeknown to the vessel operators. To emphasise the hazard, Shapiro *et al.* (1997) noted that a 4 tonne anchor on a 5000 tonne ship could penetrate 5 m into a soft muddy seabed posing a threat to any cables along a vessel's course. Such a case appears to have occurred in 2008 when a ship dragged its anchor across the Mediterranean seabed between Tunisia and Sicily and broke three cables (Orange, 2008). At least 14 nations suffered loss of fibre-optic connectivity. Particularly hard-hit were internet-based businesses such as out-sourcing and call centres in India and Pakistan. Another example of anchoring impacts followed the economic downturn of 2008–2009. International trade declined and cargo-less vessels were laid up around major ports. Many vessels anchored outside port limits (OPL) to avoid pilot and port charges (West of England, 2009). Off Singapore and Malaysia, OPL anchorages became congested. The problem was exacerbated by strong tidal currents that heightened the risk of vessel collision and cable damage as ships dragged their anchors or swung on their moorings. Resultant anchor damage to cables amounted to almost $US4.5 million (Lloyds List, 2009). To resolve the problem, Malaysia, Singapore and Indonesia approached the International Maritime Organization to direct ships to designated anchorages where vessels were better regulated and cables were either absent or well protected.

Protection of subsea fibre-optic cables is a multifaceted process that involves some combination of physical protection, legal protection, active preventative measures and ongoing communication with other seabed users including the public. Physical protection typically centres on the armouring of a cable, and where possible, burying it beneath the seabed to a depth that protects it from a known hazard. Where cables cannot be buried, for example in rocky areas, they may be protected by concrete mats or rock armour, or inserted in iron pipes. For environmentally sensitive coasts, cables may be placed under the littoral zone seabed via directional drilling from shore (e.g. Austin *et al.*, 2004).

Cables within the EEZ (200 nautical mile (370 km) limit) or Territorial Sea (12 nautical mile (22 km) limit) may be afforded legal protection through the creation of cable protection zones (see International Law and Submarine Cables). In the case of Australia, protection zones exclude activities considered hazardous to cables, and departures from the law are punishable by fines and/or ten years imprisonment (ACMA, 2015). Of course a protection zone is only successful through effective policing and education of seabed users (e.g. Transpower and Ministry of Transport, 2013). Policing may involve periodic over-flights, stationing of permanent observers and/or public notification of hazardous activities. Development of new technologies, in particular the Automatic Identification System (AIS) and Vessel Monitoring System (VMS) now permit monitoring of vessels in real time (Drew, 2013). AIS is required for ships over 299 gross tonnes and provides frequent updates via VHF radio of a vessel's name, number, position, speed, direction and other data. Software plots a ship's location and heading and thus provides a warning should a vessel pose a risk; those data are also archived to provide evidence should a vessel be charged with damaging a cable.

Education is an ongoing process and occurs on several fronts; (i) provision of plain-language information on cables and their importance for policy makers, the public and other seabed users (ICPC, 2013; Burnett *et al.*, 2013), (ii) provision of cable locations on navigational charts and official notices to mariners (e.g. ACMA, 2015) and (iii) direct communication and collaboration between the cable industry representatives and other seabed users such as the fishing and offshore wind-farm industries. Those initiatives result in the sharing of knowledge about the operations of the involved parties and have produced guidelines to improve the safety of seabed users and infrastructure (Drew and Hopper, 1996; OFCC, 2007; The Crown Estate, 2012).

Environmental aspects of cables

In traversing the ocean, cables encounter a suite of environments that range from the highly dynamic, wave-dominated surf zone to extreme depths of 5000 m and more where water temperatures are <2°C, pressures are 500 times that at sea level, and currents, if present, are typically slow although they may be subject to strong periodic perturbations (e.g. Hollister and

McCave, 1984). For practical purposes, cables can be separated into (i) those laid on the seabed usually in water depths >*ca.* 2000 m beyond the present limit of bottom trawl fishing, but also in shallower water where cable burial is not possible or needed due to unsuitable seabed conditions, the presence of a cable protection zone or an absence of other seabed users whose activities may pose a risk and (ii) cables buried under the seabed for protection from such activities that occur mainly in water depths <200 m but can extend to *ca.* 2000 m.

Cables laid on the seabed

Once deployed on the seabed, cables are exposed to physical and biological forces (Carter *et al.*, 2009). In the shallow waters (*ca.* <30 m) of the inner continental shelf, tides in association with storm-forced ocean currents and waves move seabed sediment that can abrade, bury, expose or undermine cables. The last phenomenon can produce suspensions that sway under current/wave action and eventually induce cable fatigue (e.g. Carter *et al.*, 1991; Kogan *et al.*, 2006). In depths down to *ca.* 130 m – the global average depth limit of the continental shelf – effects of storm-forced currents and waves decrease but can nonetheless disturb the seabed under extreme storms. If the continental shelf has a strong supply of sediment, as is the case for shelves of the circum-Pacific rim (e.g. Milliman and Syvitski, 1992), the rapid accumulation of sediment (up to 1 cm/year) can bury a cable.

In the deep ocean (>2000 m), the deposition of sediment is considerably slower (e.g. 0.001–0.004 cm/year). However, higher rates occur locally where land-derived sediment is discharged to depth via (i) submarine canyons linked to large rivers and (ii) submarine landslides (e.g. Heezen and Ewing, 1952; Carter *et al.*, 2012). These settings can be found off major rivers such as the Zaire (Droz *et al.*, 1996), but the prime sites are off earthquake- and storm-prone margins such as those bordering the Pacific Ocean. There, small rivers discharge a disproportionally large volume of sediment because of unstable landscapes and pronounced rainfalls. In such instances cables may receive rapid influxes of mud and sand from submarine landslides and mud-laden flows or *turbidity currents* with sufficient power to break cables (see Natural Hazards). Elsewhere, cables may be subject to locally intensified, deep-ocean currents that flow along the western boundaries of the major oceans (Hogg, 2001) and are known to erode and deposit sediment especially during periods when the flow is reinforced by powerful eddies (Hollister and McCave, 1984; Carter and McCave, 1997).

Any interaction of surface-laid cables with the marine biota appears to be negligible to minor judging by several cable-based studies. Using sediment cores and video footage collected by a remotely operated vehicle along a subsea cable off California, Kogan *et al.* (2006) showed that animals living in or on the seabed 1m and 100 m from the cable were not statistically different. In a similar vein, Andrulewicz *et al.* (2003) likewise reported no change in the abundance, composition and biomass of organisms before and one year after a subsea power cable deployment. Grannis (2001) reached similar conclusions regarding the biota along a cable off the north-eastern USA. Where cables remain uncovered by sediment they can act as substrates for encrusting organisms as long as the cable is within the depth range of an organism. As a consequence, recovered cables have been a source of specimens from parts of the ocean seldom visited by researchers (e.g. Levings and McDaniel, 1974).

Surface laid cables are exposed to fish, in particular sharks and marine mammals. Deployment of the first trans-ocean fibre-optic cable was disrupted by shark attacks in 1985–1987 off the Canary Islands (Marra, 1989). Bites from the deep-dwelling *crocodile shark*, identified from its teeth embedded in the cable sheath, were sufficient to damage the cable and force repairs. Why the fish attacks took place remains unclear, but they prompted a redesign of deep-water cables that improved protection against fish bites. The interaction with marine mammals was highlighted by Heezen (1957) who reported on a series of cable faults caused mainly by sperm whales whose remains were entangled in the recovered cables. Analysis of fault records revealed the entanglements were confined to telegraphic era cables and were located mainly on the continental shelf and upper continental slope where cables had been previously repaired – a factor that suggests the whales may have been caught in coils of cable formed from the repair. Cable fault databases show a cessation of whale entanglements with the introduction of coaxial and fibre-optic systems (Wood and Carter, 2008). This marked change resulted from improved design and laying techniques that prevented coiling, and cable burial beneath the seabed.

Comprised of high density, ultra-violet resistant polyethylene sheathing without antifouling agents, modern cables are chemically stable. When samples of different cable types – some with cut ends sealed and others exposed – were immersed in 5 litre containers of natural seawater and tested for leached metals. Only zinc was detected and this was from the galvanised wire-armoured samples with exposed ends (Collins, 2007). Up to 11 parts per million Zn were measured initially whereas iron and copper were at natural background levels, i.e. no leaching was detected. Bearing in mind that (i) in the open ocean Zn concentrations would be much lower due to dilution, (ii) the rates of Zn leaching declined markedly after ten days' exposure in the seawater containers and (iii) Zn is a common trace element in seawater that is essential for marine biological processes (Morel and Price, 2003), the amount of leachate recorded in the laboratory tests is small.

Cables buried under the seabed

The protective burial of cables on the continental shelf and slope usually involves mechanical ploughing. A plough, towed by a cable ship, opens a furrow in the seabed into which the cable is inserted. In soft sediments, the furrow wall collapses to encase the cable whereas more consolidated materials may only partially collapse. In both instances, burial is facilitated by natural sediment accumulation. Ploughing disturbs the seabed, the extent of which varies with substrate conditions, plough type and the depth of burial, which is dictated by the nature of the expected hazard (e.g. Rapp *et al.*, 2004). For heavily fished areas where the trawl doors penetrate *ca.* 0.5 m into the seabed, a cable may be buried 1m deep in which case the plough share will have a disturbance strip *ca.* 0.3 m wide. In addition, the skids that support the plough share can disturb the immediate seabed surface over a 2 m to 8 m wide strip.

The other main burial technique is jetting. High pressure water jets, commonly incorporated on a remotely operated vehicle (ROV), liquefy seabed sediments allowing the cable to sink to a required depth. The technique is used for substrates that are unsuitable for mechanical ploughing such as steep slopes, very soft muddy sediments and water depths *ca.* >1000 m (Hoshina and Featherstone, 2001). Jetting is also used to bury repaired sections of cable. Again, there is some disturbance relating to the width of the jetted furrow and dispersal of turbid water whose extent and effect on biota will depend upon local oceanographic conditions.

Burial disturbance should be viewed in context. Burial is a restricted and non-repetitive activity in the 20–25 year design life of a cable unless a repair is required. In contrast, bottom trawl fishing has a wider footprint and is a repetitive process (e.g. Puig *et al.*, 2012). Another consideration is the ability of the seabed to recover naturally from burial-related disturbance. For sheltered coasts, recovery from ploughing of mangrove swamps and salt marshes ranges from 2 to 7 months and 1 to 5 years respectively (Dernie *et al.*, 2003; Ecoplan, 2003). On exposed coasts down to *ca.* 30 m water depth, wave and current action shift sediment on a daily to annual basis resulting in amelioration or removal any burial scars (Carter and Lewis, 1995; CEE, 2006). The benthic fauna are also adapted to the frequently mobile sediments and appear to be unaffected by cable deployment as evinced by Andrulewicz *et al.* (2003). For the remainder of the continental shelf out to *ca.* 130 m depth, the influence of waves and wind-driven currents declines with depth although tides are omnipresent and can instigate daily movement of sediment in tide-dominated regions such as the English Channel and Cook Strait, New Zealand (Grochowski *et al.*, 1993; Carter and Lewis, 1995). Plow scars on shelves with a substantial supply of sediment may be infilled by the natural deposition of mud that can locally reach 1 cm/year or more (e.g. Huh *et al.*, 2009). At the shelf edge, seabed recovery may be facilitated by tidal and ocean currents that are intensified against the edge topography. For shelf areas with a limited sediment supply and weak or infrequent current/wave action, recovery is slower (e.g. NOAA, 2005; California Coastal Commission, 2007).

Cable life cycle

A cradle-to-grave analysis of fibre-optic cables was made by Donovan (2009) to assess the environmental effects – both positive and negative – of cable manufacture, operation and recovery. Potential environmental effects are associated mainly with the electrical power required to operate cable terminal stations and with fuel used by cable ships for laying and maintenance. Taking those and other factors such as cable manufacture and recycling into account, it was estimated that 7 g of carbon dioxide equivalents were released for every 10,000 gigabit km, i.e. the transmission of 1 gigabit of data over 10,000 km of cable. The relevance of this carbon dioxide equivalent emission becomes apparent when a cable-based teleconference between Stockholm and New York is compared to an equivalent face-to-face meeting (Donovan, 2009). Because face-to-face meetings involve air and other travel, the carbon dioxide equivalent emissions were 1920 kg compared to 5.7 kg for the teleconference.

Natural hazards

Although natural hazards cause <10 per cent of all cable faults (Kordahi *et al.*, 2007) they become more prominent in depths >1000–2000 m, where human operations are markedly reduced. Furthermore, a major hazard such as a submarine landslide can damage multiple cables to cause a widespread reduction or even loss of internet and communication traffic. This was the case for earthquake-triggered submarine landslides and turbidity currents off Algeria 2003 (Dan *et al.*, 2003; Cattaneo *et al.*, 2012), southern Taiwan, 2006 (Hsu *et al.*, 2009) and northern Japan, 2011 (studies underway).

Hazards from the coast to abyssal ocean

On the continental shelf, cables are exposed to mobile sand and gravel (Allan, 2000) that can (i) abrade, (ii) bury or (iii) undermine cables to produce suspensions that may result in cable fatigue (e.g. Kogan *et al.*, 2006). However, improved design, construction and deployment have produced robust shallow-water cables.

Severe storms are a major threat to coastal and shelf cable infrastructure. Winds increase wave and current action to enhance sediment mobility. During Hurricane Iwa (1982), wind-forced waves and currents set off submarine landslides and turbidity currents that swept down the continental slope off Oahu, Hawaii to break six cables (Dengler *et al.*, 1984). Winds and changes in barometric pressure also set up storm surges as occurred during Typhoon Nargis (2008) when a 4 m high storm surge passed over the Irrawaddy Delta to damage a cable station (Ko, 2011). Hurricane Sandy (2012) also generated a 4 m high surge, which together with 180 mm of rain, flooded lower Manhattan (NASA, 2012; USGS, 2014). At least one fibre-optic link was damaged, but a key impact related to the flooding of several major cable-fed datacenters (Cowie, 2012).

River floods are also a hazard especially where a river is linked directly to a submarine canyon across which cables pass. Typhoon Morakot (2009) was the wettest tropical cyclone on record for Taiwan. Almost 3 m of rain generated exceptional floods that caused the Gaoping River to discharge an estimated 150 million tonnes of sediment in just six days (Carter *et al.*, 2012). River discharge eventually transformed into two turbidity currents that swept down the submarine Gaoping Canyon to damage eight cables along a 370 km long pathway in water depths down to 4200 m.

Submarine landslides and turbidity currents are also triggered by earthquakes, so it is unsurprising that such occurrences are relatively common in seismically active regions especially where tectonic plates collide as is the case for the circum-Pacific Ocean and parts of the Mediterranean region. However, the textbook example is from the comparatively stable Grand Banks, Newfoundland, which was shaken by a magnitude M7.2 earthquake in 1929. The shock set off subsea landslides that immediately caused 12 faults in Atlantic telegraphic cables (Heezen and Ewing, 1952; Piper *et al.*, 1985). Landslide debris contributed to a major turbidity current that broke a further 16 faults as it flowed 650 km over the seabed into water depths of over 5000 m. Current speeds of up to 65 km/hour were achieved en route. Since this pioneering set of observations, earthquakes have been implicated in a range of cable-damaging events, e.g. Orleansville (Heezen and Ewing, 1955), Papua-New Guinea (Krause *et al.*, 1970) with one of the more recent being the 2006 Hengchun earthquake (M7.0) off southern Taiwan (Hsu *et al.*, 2009). For the latter event the main shock was also accompanied by the near-instantaneous cable failures (three). Several turbidity currents followed with some possibly triggered by aftershocks. These debris-choked currents flowed down Gaoping Canyon and into the Manila Trench to cause a total of 19 cable faults. Hengchun was followed three years later by Typhoon Morakot (2009) and in 2010 by another turbidity current that broke nine cables. Clearly the ocean floor off southern Taiwan, which is a major cable corridor, is a highly hazardous region.

Offshore earthquakes can also generate tsunami that pose a risk to coastal and continental shelf telecommunications. The 2004 Indonesian mega-earthquake (M9.1–9.3) and tsunami damaged terrestrial telecommunications and possibly a subsea cable off South Africa (M. Green, BT, personal communication). Another tsunami, this time formed by the 2011 Tohoku mega-earthquake (M9.0) off northern Japan, extended up to 5 km inland and reached surge heights of up to 15 m (Tanaka *et al.*, 2012). Such a devastating inflow of water severely damaged at least one cable landing station as well as fixed line and mobile phone infrastructure. In addition, submarine telecommunications were damaged (BBC, 2011), but the full extent and specific cause(s) of the damage (landslide, turbidity current, tsunami) have yet to be determined.

Damage from active submarine volcanoes and icebergs/sea ice is rare although the latter hazard may come to the fore as remote Arctic areas are connected to the global network (see Hazards under climate change). Submarine volcanic activity is widespread especially along mid-ocean ridges where tectonic plates diverge and around the Pacific rim. Volcanoes pose potential hazards through eruptions, landslides, hot water vents and other phenomena including tsunami such as occurred during the eruption of Krakatau (Krakatoa) in 1883 (Winchester, 2003). Following a main blast, a tsunami that locally reached 35 m height, radiated southwards across the Indian Ocean severing the local subsea telegraphic link with the rest of the world. However, direct impacts of submarine volcanism can be minimised because volcanic structures have distinctive geological and geophysical features and are avoided by cable route planners.

Hazards under climate change

Coastal and ocean environments are responding to the present phase of climate change as documented by the IPCC (2013) and a plethora of ongoing research.

Meltwater from glaciers and ice sheets, together with thermal expansion of the ocean have produced a global average rise in sea level of 3.2 mm/year (University of Colorado, 2015). Tectonic plate movements, ocean currents, gravitational effects among others also locally affect sea level; hence the need to determine local conditions when assessing the risk posed to coastal cable infrastructure. As sea level rises, coasts become more prone to erosion and flooding as demonstrated by data from Australia that suggest the frequency of extreme high sea level events increased by a factor of 3 in the twentieth century (Ocean Climate Change, 2012).

Ocean and atmospheric warming are likely to lead to more intense and/or frequent storms (IPCC, 2013) that will strengthen wave and current activity at the coast and adjacent continental shelf. In addition, stronger winds and associated drops in barometric pressure will enhance storm surges of which Hurricane Sandy may be a harbinger judging by a recorded increase of extreme climatic events in the northeast USA (NOAA, 2012).

Warming is likely to affect rainfall patterns and by association river discharge as exemplified by Typhoon Morakot (Carter *et al.*, 2012). However, although Morakot was the wettest cyclone on Taiwanese records it cannot be confidently attributed to modern climate change although its characteristics are consistent with climate projections.

The core of strong westerly winds has moved towards the poles resulting in changes in wave and current regimes (Toggweiler *et al.*, 2006; Thompson *et al.*, 2011). The Southern Hemisphere, for example, is witnessing stronger wave activity and strengthened ocean currents (e.g. Böning *et al.*, 2008) – responses that will have a bearing on coastal and shelf settings as well as cable laying and maintenance operations.

In addition to direct environmental effects, climate change is altering other seabed activities and hence is changing the risk such activities pose to cables. Wind turbine farms are expanding as nations seek to reduce greenhouse emissions, meet increasing demand for electrical power and establish more secure energy supplies. The growth of wind farms and other renewable energy schemes, as well as plans to create new submarine energy grids (e.g. IEEE Spectrum, 2010), will restrict the choice of viable telecommunication cable routes and will impact upon laying and maintenance operations. Industrial fisheries may also be responding to climate change (e.g. Frost *et al.*, 2012). Ocean warming in the Northern Hemisphere has encouraged southern fish species to migrate north, for example, previously Mediterranean-dwelling anchovies now occur in commercial quantities off the UK. Furthermore, deep-dwelling fish are increasing their preferred depth by 3.6 m/decade. Such trends are likely to alter the style and depth range of fishing practices.

Ocean/climate change is also bringing new opportunities for cables. The Arctic Ocean has lost much of its summer sea ice and in September, 2012, reached its minimum extent since 1978 when satellite monitoring began (NSIDC, 2012). Ice loss reflects a warmer ocean and increased storminess, and if the current trend continues, the summer Arctic could be ice-free within a decade. Such a marked environmental shift has fostered plans to install fibre-optic links with remote Arctic communities and the rest of the world. The Russian Optical Trans-Arctic Submarine Cable System (ROTACS), for instance, is planned to link Tokyo with the Russian Arctic and London (*New Scientist*, 2012) with branches to South Korea and China.

Telecommunications in an evolving seascape

Humanity's increasing presence in and on the ocean has placed pressures on the environment especially in relation to the extraction of living and non-living resources (e.g. UNEP, 2006). One response has been the creation of Marine Protected Areas (MPA), which presently encompass *ca.* 3.2 per cent of the global ocean (Marine Reserves Coalition, 2012). The nature of that protection varies among nations. In the case of Australia, whose MPAs extend over 3.1 million km^2 of ocean and seabed (Australian Government, 2015), protection is afforded at different levels ranging from MPAs where all commercial activities are prohibited to those where limited activities are permitted except those that are damaging to the environment.

The laying and maintenance of submarine telecommunications cables are generally permitted activities in multi-purpose protected areas, especially in light of their designation as *critical infrastructure*, their low environmental impact (OSPAR, 2008; Carter *et al.*, 2009; Burnett *et al.*, 2013) and their special status under UNCLOS (see International law and cables).

Marine research, especially that related to climate/ocean change, natural hazards and resource assessment, has been bolstered by the development of ocean observatories. These fibre-optic and power cable-based systems have been designed for long-term (20–25 years) monitoring and *in situ* experiments, the data from which are available in near-real time for the public and science community (Carter and Soons, 2013). Although subsea communications cables have been used to measure currents and thermal structure of the ocean since the 1980s (Baringer and Larsen, 2001; Howe, 2004), it has only been in the last five years that large observatories capable of conducting multidisciplinary research, have come to the fore. One of the first cabled observatories is the Monterey Accelerated Research System (MARS) situated in Monterey Bay, California (MARS, 2015). It began operation in 2008 and is based on a *node* located on the seabed at 891 m depth. Shaped like a truncated pyramid and weighing several tonnes, the node is a trawler-resistant submarine housing into which various sensors and experiments can be plugged. It supplies communications and power, and is connected to a shore-based receiving centre by a 52 km long fibre-optic/power cable.

On a larger scale is the North East Pacific Time-series Undersea Network Experiments (NEPTUNE) observatory, which began operation in 2009. NEPTUNE is presently the largest observatory with an 812 km long fibre-optic/power cable that interconnects five nodes distributed from the continental shelf to abyssal plain at 2660 m depth (Ocean Networks Canada, 2015). In that configuration, NEPTUNE covers a range of key marine environments with experiments tailored for a specific setting. For example, the node in the submarine Barkley Canyon (400–1000 m depth) is the hub for research into (i) the movement of water and sediment along the canyon, (ii) the composition and change of canyon ecosystems, (iii) gas hydrates – mixtures of methane gas and ice that are a potential source of hydrocarbons and (iv) the impacts of earthquakes and tsunami. Such information is relevant to the cable industry by virtue of the hazards posed by landslides and turbidity currents generated by unstable sediments on submarine slopes and canyons, and by the potential mining of gas hydrates as an energy source.

Whatever the activity, the increasing human presence offshore has prompted regulatory regimes such as Marine Spatial Planning (MSP). These regimes provide frameworks to address coastal and marine issues concerned with environmental conservation and sustainability, commercial and recreational activities as well as scientific research. Implementation of MSP is underway in Europe, North America and Oceania among other regions (e.g. DEFRA, 2009; Ministry for the Environment, 2012). The USA, for example, created a National Ocean Council to implement policy concerning stewardship of the Great Lakes, coasts and oceans (National Ocean Council, 2012). Policy aims are wide ranging; from protecting and restoring ocean biodiversity to bettering the public's knowledge of its offshore estate. Of relevance to submarine telecommunications are; (i) the support of sustainable, safe, secure and productive access to, and uses of the ocean and (ii) the exercise of rights and jurisdiction in accordance with international law that involves respect for and preservation of navigational rights and freedoms. The latter point is critical in that while not a signatory to UNCLOS, the USA recognises the importance of that convention as 'the bedrock legal instrument governing activities on, over and under the world's oceans'. There is also recognition of cables as critical infrastructure, which DEFRA (2011) describes as 'socially and economically crucial to the UK'. Both the legal and critical infrastructural aspects, along with acknowledgement of the nil to low environmental impact of submarine cables (e.g. DEFRA, 2011), should not disadvantage submarine cables under MSP.

Notes

1 The Cable Convention continues to be widely used in the cable industry. While its essential terms are included in UNCLOS, the Cable Convention remains the only treaty that provides the detailed procedures necessary to implement them. *See* Art. 5 special lights and day shapes displayed by cable ships; minimum distances ships are required to be from cable ships; Art. 6 minimum distance ships are required to be from cable buoys; Art 7 procedures for sacrificed anchor and gear claims, Art. 8 competency of national courts for infractions; and Art. 10, procedures for boarding vessels suspected of injuring cables and obtaining evidence of infractions. Article 311(2) of UNCLOS recognises the continued use of these provisions, which are compatible and supplement UNCLOS.

2 Articles 21, 51, 58, 79, 87, 112–115 and 297.

3 Article 79(4).

4 Articles 51, 58, 79, 87, 112–115, and 297.(1)(a).

5 The term laying refers to new cables while the term maintaining relates to both new and existing cables and includes repair. Nordquist, *United Nations Convention on the Law of the Sea 1982: A Commentary*, Vol II (1993) at p. 915.

6 The origin of the term 'culpable negligence' is found in Renault, Louis, The Protection of Submarine Telegraphs and the Paris Conference (October–November 1882) at p. 8 where reference is made to two early English cases *Submarine Cable Company v. Dixon, The Law Times*, Reports, Vol. X, N.S. at 32 (Mar. 5, 1864) and *The Clara Killian*, Vol. III L.R. Adm. and Eccl. at 161 (1870). These cases hold that culpable negligence involves a failure to use ordinary nautical skill which would have been used by a prudent seaman facing the situation that caused the cable fault. Since the term 'culpable negligence' was adopted in UNCLOS without discussion, it is reasonable to assume that the same standard applies under UNCLOS.

7 Article 79(3).

8 Telecommunications Act of 1997, including amendments up to Act No. 169 of 2012.

9 Submarine Cable and Pipeline Protection Act (16 May 1966).

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